SECTION 4

NON-ROAD MOBILE SOURCES

4.1 Introduction

Non-road mobile sources represent a large and diverse set of off-road vehicles and non-stationary equipment. Emission estimates for this source sector account for exhaust emissions (VOCs, NOx, and CO) from engine fuel combustion and evaporative VOC emissions. The evaporative emissions are associated with equipment fuel tanks, fuel lines, and refueling of non-road equipment using portable fuel containers. Finally, the methodology for estimating evaporative emissions from commercial marine vessel (CMV) loading and transport of petroleum products is included within this section due to the large overlap with CMV engine exhaust emission estimation methodologies. However, SCCs associated with loading and transport of petroleum products are grouped with other non-point source SCCs. Therefore, loading and transport emissions are included in the non-point source NIF files and summaries under the Gas Marketing category.

4.1.1 Source Categories

Non-road vehicles and equipment are grouped into four source category types for the purpose of developing emission estimates. These include:

- **Aircraft –** Commercial, military, and private aircraft are considered under this source category.

- **Locomotives –** Commercial line haul and yard locomotives are considered under this source category.

- **Commercial Marine Vessels (CMVs) –** Various types of vessels that navigate the Delaware Bay and River and the Chesapeake and Delaware Canal are included under this source category. Recreational boats are included in the next category.

- **Other Off-road Vehicles and Equipment –** All other off-road emission sources are accounted for through the use of EPA's NONROAD model. The NONROAD model compiles off-road equipment pertinent to Delaware into the following subcategories:

    - Recreational (land-based);
    - Construction and Mining;
    - Industrial;
    - Lawn and Garden;
    - Agricultural;
    - Commercial;
    - Logging;
    - Airport Ground Support;
    - Recreational Marine; and
    - Railway Maintenance.

Individual equipment SCCs covered in the NONROAD model are further broken down by the fuel type, including 2-stroke gasoline, 4-stroke gasoline, diesel, liquefied petroleum gas (LPG), and compressed natural gas (CNG).

4.1.2 Emission Estimation Methodologies

The 1999 Periodic Emission Inventory (PEI) served as the starting point for non-road source category selection and methodology development. No new sources were added to Delaware's off-road mobile source inventory. However, new methods were applied to some existing source categories, such as the CMV category, and emission factors were updated where available. Also the NONROAD model went through several versions during the development of the 2002 inventory with important improvements in the latest version (NONROAD2005).

Similar to the estimation of stationary non-point emissions, off-road equipment emissions were estimated by multiplying an indicator of collective activity within the inventory area for a source category by a corresponding emission factor. The indicators of activity for off-road sources include landing and take-offs (LTOs), vessel port-of-calls, time-in-mode (TIMs, which are pertinent to aircraft and CMVs), gross ton miles (locomotives), equipment populations and economic activity (both pertinent to NONROAD equipment) that can be correlated with the emissions from that source. The corresponding emission factors are amount of pollutant (either grams or pounds) per unit of fuel used (locomotives and military/commercial aircraft), per LTO (air taxi and general aviation) or per unit of power output in brake horsepower or kilowatt-hours (NONROAD equipment and CMVs, respectively).

A major portion of the work involved in creating the 2002 non-road source inventory was in collecting activity data for each source category. The activity data gathered was related to the type of emission factors available and, in many cases, obtained from local sources. The details of gathering activity data for each source category are presented within this section of the report.

There are no point source data that must be backed out of the non-road mobile source sector. Even though there are airports that report as a point source (e.g., the Dover Air Force Base), their reported emissions do not include ground support equipment or aircraft engine and evaporative emissions. Also, aircraft emissions are estimated only for LTOs that take place at a Delaware airport. Emissions from aircraft that transit Delaware airspace are not included in Delaware's inventory.

Source activity may fluctuate significantly on a seasonal and weekly basis. As an example, most residential lawn and garden equipment usage takes place during the warmer months of the year. However, that activity is also more prevalent on weekends, thus reducing the summer season weekday (SSWD) emissions value. Because off-road source emissions are generally a direct function of source activity, seasonal changes in activity levels were examined closely. Emissions were calculated on an annual basis and temporal allocation profiles were developed to estimate SSWD emissions.

4.1.3 2002 Emissions Summary

Table 4-1 provides a statewide summary of the 2002 annual (tons per year, TPY) and SSWD (tons per day, TPD) emissions for aircraft, locomotives, commercial marine vessels, and all equipment emissions estimated using EPA's NONROAD model. The non-road sector is a significant contributor to ozone precursors in Delaware. The totals may not match the sum of the individual values due to independent rounding.

Table 4-1. Summary of 2002 Statewide Emissions from Non-road Sources

Source Categories	VOC		NO_X		CO	
	TPY	TPD	TPY	TPD	TPY	TPD
NONROAD Model Equipment	7,531	25.28	5,798	21.40	65,954	258.10
Aircraft	291	0.94	970	3.18	1,570	5.11
Locomotives	57	0.16	1,097	3.02	120	0.33
Commercial Marine Vessels	140	0.39	9,118	25.20	1,275	3.53
NON-ROAD SECTOR TOTAL	**8,019**	**26.77**	**16,982**	**52.79**	**68,918**	**267.06**

Figures 4-1 presents the top seven VOC categories based on SSWD daily emissions. The lawn and garden equipment category accounts for 43% of the statewide SSWD daily VOC emissions from the non-road sector. The lawn and garden category is comprised of a large equipment population made up of 2-stroke and 4-stroke gasoline engines, which produce most of the VOC emissions for this category.

The recreational marine category, also referred to as pleasure craft, accounts for 25% of the statewide SSWD daily VOC emissions from the non-road sector, due to the large number small boats that use 2-stroke gasoline engines. A large amount of the annual activity of lawn and garden equipment and pleasure craft takes place within the peak ozone season, further increasing the SSWD daily values compared to other categories.

Figure 4-1. 2002 Statewide VOC SSWD Emissions by Non-road Source Category

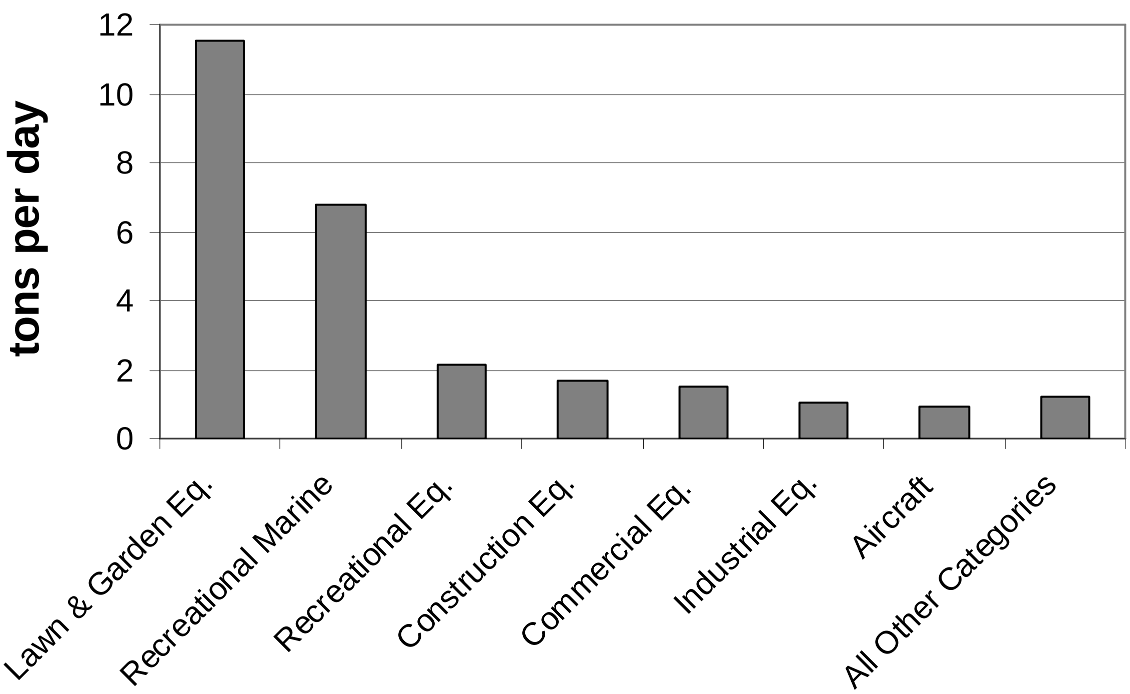
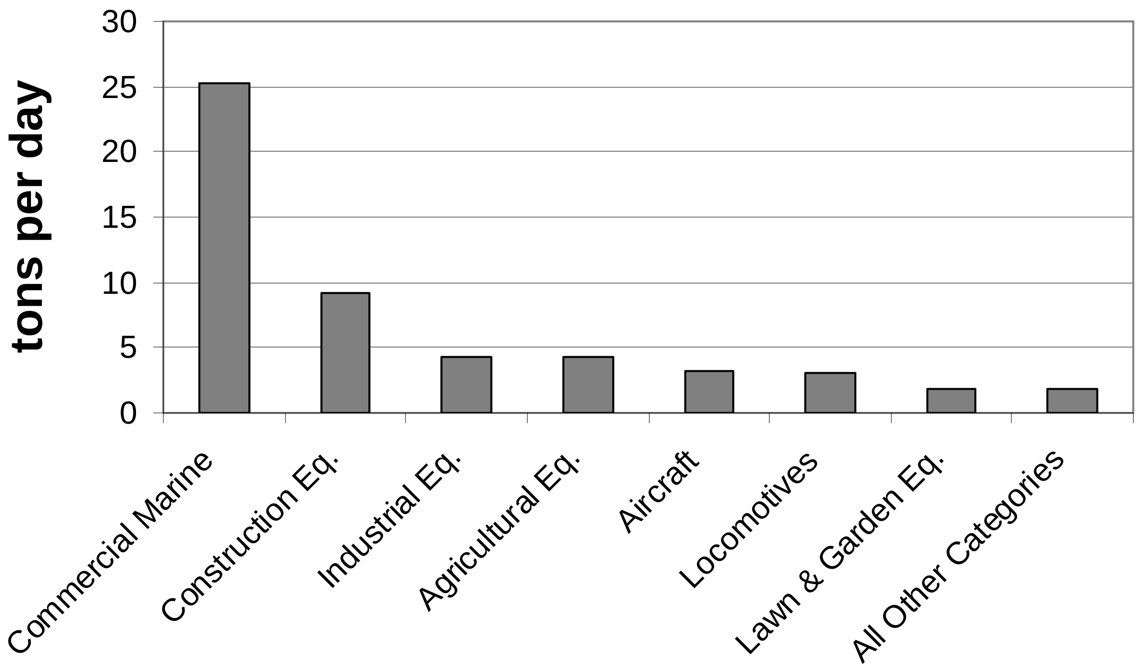


Figure 4-2 presents the top seven NO_x categories based on SSWD daily emissions. The commercial marine vessel (CMV) category accounts for 48% of the statewide SSWD daily NO_x emissions from the non-road sector. The Delaware River and Bay is one of the largest port areas in the United States. Thousands of ships each year ply Delaware waters en route to ports in Wilmington, Philadelphia, Camden, Trenton, and other locations along the highly industrialized Delaware River. The predominant fuels used by CMVs are diesel and residual oil. NOx emission rates for CMV engines combusting these fuels are high compared to rates for the combustion of gasoline and other fuels (liquid propane and natural gas).

The construction equipment category accounts for 17% of the statewide SSWD daily NO_x emissions from the non-road sector, due to the large diesel equipment population. The construction category includes commercial, residential, and road construction equipment.

Figure 4-2. 2002 Statewide NO_X SSWD Emissions by Non-road Source Category



Tables 4-2 through 4-4 provide the emissions data for each of the three counties in Delaware. The totals may not match the sum of the individual values due to independent rounding.

Table 4-2. Summary of 2002 Non-road Emissions for Kent County

Source Categories	VOC		NO_X		CO	
	TPY	TPD	TPY	TPD	TPY	TPD
NONROAD Model Equipment	1,360	4.30	1,487	5.68	9,974	37.39
Aircraft	235	0.76	945	3.10	774	2.63
Locomotives	11	0.03	206	0.57	22	0.06
Commercial Marine Vessels	30	0.08	2,071	5.67	291	0.80
KENT COUNTY TOTAL	**1,636**	**5.17**	**4,709**	**15.02**	**11,061**	**40.88**

Table 4-3. Summary of 2002 Non-road Emissions for New Castle County

Source Categories	VOC		NO_X		CO	
	TPY	TPD	TPY	TPD	TPY	TPD
NONROAD Model Equipment	3,250	11.76	2,480	8.69	37,075	149.01
Aircraft	53	0.16	24	0.08	683	2.05
Locomotives	41	0.11	776	2.13	85	0.23
Commercial Marine Vessels	72	0.20	4,999	13.72	767	2.10
NEW CASTLE COUNTY TOTAL	**3,415**	**12.24**	**8,279**	**24.62**	**38,609**	**153.40**

Table 4-4. Summary of 2002 Non-road Emissions for Sussex County

Source Categories	VOC		NO_X		CO	
	TPY	TPD	TPY	TPD	TPY	TPD
NONROAD Model Equipment	2,921	9.22	1,831	7.03	18,906	71.69
Aircraft	4	0.01	1	< 0.01	113	0.43
Locomotives	6	0.02	115	0.32	13	0.03
Commercial Marine Vessels	38	0.11	2,047	5.81	217	0.63
SUSSEX COUNTY TOTAL	**2,968**	**9.36**	**3,994**	**13.15**	**19,248**	**72.79**

4.2 NONROAD Model Equipment

DNREC began the development of non-road source emissions using the draft NONROAD2002a model version (EPA, 2003) and developed annual and SSWD emission estimates based on that version. The documentation in this section is based on the efforts to develop those estimates. However, in early 2006 MANE-VU contracted with E.H. Pechan and Associates to develop new 2002 annual emission estimates based on the use of NONROAD2005, the newly released version of the model (EPA, 2005). These new estimates were used for the regional attainment demonstration modeling. These estimates included the same Delaware-specific inputs that were developed for the running of the NONROAD2002a model version. In order to be consistent with the modeling effort, the annual emissions developed by MANE-VU using NONROAD2005 are the emissions Delaware is submitting in its SIP and included in this report. SSWD values were developed by summing the NONROAD2005 monthly emissions for June, July, and August and applying the weekly allocation profiles used to develop the original SSWD daily values.

Most equipment covered by the NONROAD model is powered by diesel-fueled compression-ignition engines or gasoline-fueled spark-ignition engines. Engines fueled by compressed natural gas (CNG) and liquefied petroleum gas (LPG) engines are also included in the NONROAD model. Table 4-5 lists general SCCs addressed by the NONROAD model. Equipment categories are typically defined at the 7-digit SCC level (with recreational marine and railway maintenance being exceptions) and specific equipment are defined at the 10-digit SCC level.

Table 4-5. SCCs Addressed by the NONROAD Model

Nonroad SCCs	SCC Descriptions	Nonroad SCCs	SCC Descriptions
2260xxxxxx	2-stroke gasoline engines	2268xxxxxx	CNG engines
2260001xxx	- recreational vehicles	2268002xxx	- construction equipment
2260002xxx	- construction equipment	2268003xxx	- industrial equipment
2260003xxx	- industrial equipment	2268005xxx	- agricultural equipment
2260004xxx	- lawn & garden equipment	2268006xxx	- light commercial equipment
2260005xxx	- agricultural equipment	226801xxxx	- oil field equipment
2260006xxx	- light commercial equipment	2270xxxxxx	Diesel engines
2260007xxx	- logging equipment	2270001xxx	- recreational vehicles
2265xxxxxx	4-stroke gasoline engines	2270002xxx	- construction equipment
2265001xxx	- recreational vehicles	2270003xxx	- industrial equipment
2265002xxx	- construction equipment	2270004xxx	- lawn & garden equipment
2265003xxx	- industrial equipment	2270005xxx	- farm equipment
2265004xxx	- lawn & garden equipment	2270006xxx	- light commercial equipment
2265005xxx	- agricultural equipment	2270007xxx	- logging equipment
2265006xxx	- light commercial equipment	2270008xxx	- airport service equipment
2265007xxx	- logging equipment	2270009xxx	- underground mining equipment
2265008xxx	- airport service equipment	227001xxxx	- oil field equipment
226501xxxx	- oil field equipment	2282xxxxxx	Recreational marine equipment
2267xxxxxx	LPG engines	2285xxx015	Railway maintenance equipment
2267001xxx	- recreational vehicles		
2267002xxx	- construction equipment		
2267003xxx	- industrial equipment		
2267004xxx	- lawn & garden equipment		
2267005xxx	- agricultural equipment		
2267006xxx	- light commercial equipment		
2267008xxx	- airport service equipment		

To estimate pollutant emissions, the NONROAD model multiplies equipment populations and their associated activity by the appropriate emission factors. Geographic allocation factors (GAFs) are used to distribute national equipment populations to counties/states. These factors are based on surrogate indicators of equipment populations. For example, harvested cropland is the surrogate indicator used in allocating agricultural equipment. A national average engine activity (i.e., load factor times annual hours of use) is used in NONROAD.

4.2.1 Methodology/Input Data by Equipment Category

To improve the accuracy of the model runs, default inputs were replaced in the NONROAD model option files for select parameters. In the options packet, inputs that can be replaced include: Reid vapor pressure (RVP), temperature, oxygenated fuel weight percent, Stage 2 control factors, and fuel sulfur levels. Local activity data inputs, such as equipment populations or activity (e.g., hours of use or load factors), can also replace default values in the model.

NONROAD model option files were prepared to account for temperatures and fuel characteristics representative of each county for each of the four seasons (winter, spring, summer, and fall). Temperature and fuel input values for each three-month period (December-February, March-May, June-August, and September-November) were averaged to estimate seasonal values. Minimum, maximum, and average temperatures per month were obtained from the National Climatic Data Center (NCDC, 2003). Table 4-6 presents a summary of the temperature and fuel characteristic data used for each season and for each of the three counties.

Table 4-6. NONROAD Model Temperature and Fuel Characteristic Input Values by County and Season

County	Season	Oxygen Weight %	RVP psi	Gasoline Sulfur ppm	Temperature, degrees F		
					Minimum	Maximum	Average
Kent	Summer	2.1	6.76	130	66	85	77
Kent	Autumn	2.06	8.03	138.38	49	65	59
Kent	Winter	1.87	13.41	174	30	46	40
Kent	Spring	2.02	9.29	146.76	44	64	57
New Castle	Summer	2.1	6.76	130	66	85	76
New Castle	Autumn	2.06	8.03	138.38	48	64	56
New Castle	Winter	1.87	13.41	174	29	45	37
New Castle	Spring	2.02	9.29	146.76	44	63	54
Sussex	Summer	1.7	6.43	134	62	86	74
Sussex	Autumn	1.63	7.76	151.33	48	67	57
Sussex	Winter	1.5	13.41	225	28	49	38
Sussex	Spring	1.57	9.09	168.67	43	66	54

For the diesel fuel sulfur level, a value of 2,500 parts per million (ppm) was used instead of the default value of 2,318 ppm currently in the NONROAD model. The 2,318 default value represents a national average including California's lower diesel fuel sulfur level, and is more appropriate for national-level runs. EPA's Office of Transportation Air Quality (OTAQ) recommends 2,500 ppm for non-California state and regional model runs. A Stage 2 control factor of 60 percent was used for all counties. This was estimated based on a control efficiency of 95 percent, a rule effectiveness of 65.3 percent and a rule penetration of 97.2 percent.

DNREC researched the availability of state and county-specific data to improve upon the default equipment populations and GAFs incorporated in the model. The following sections describe the equipment categories for which more representative state and/or county-specific data were used. Agricultural, commercial, construction, and industrial equipment categories relied on default data included in the model for population and activity estimates.

Residential Lawn and Garden Equipment

The NONROAD model uses the 1990 number of single and double-family housing units adjusted using more current population estimates to allocate residential lawn and garden equipment. DNREC obtained data from the 2000 Census on the number of single detached, single attached, and double housing units for both the State of Delaware and for Kent, New Castle, and Sussex Counties. The 2000 Census reports 246,731 single and double-family housing units for the State of Delaware, 34,679 housing units for Kent County, 151,018 housing units for New Castle County, and 61,034 housing units for Sussex County (BOC, 2003). These updated values were incorporated into the NONROAD GAF files for use in allocating 2002 state-level lawn and garden equipment populations to each county. See Table 4-7 for the county-specific values for single and double-family housing units.

Table 4-7. Delaware County Allocation Factor Data for Replacing NONROAD Defaults

NONROAD Category				
Residential Lawn and Garden	**County**	**Number of Single and Double Family Housing Units**		**Fraction**
	Kent	34,679		0.14
	New Castle	151,018		0.61
	Sussex	61,034		0.25
Recreational Equipment	**County**	**Rural Land Area, square km**		**Fraction**
	Kent	206		0.20
	New Castle	251		0.25
	Sussex	551		0.55
Golf Carts	**County**	**Golf Course Area, square km**		**Fraction**
	Kent	2		0.12
	New Castle	9		0.46
	Sussex	8		0.43
Logging	**County**	**Number of Acres Logged**		**Fraction**
	Kent	1,122		0.27
	New Castle	258		0.06
	Sussex	2,727		0.66
Aircraft Ground Support	**County**	**Commercial Aircraft LTOs**		**Fraction**
	Kent	28,975		0.28
	New Castle	63,051		0.62
	Sussex	10,350		0.10

Snow blowers

For residential snow blowers, the NONROAD model uses the number of single and double-family housing units to allocate a state's snow blower population to counties receiving at least 15 inches of snow in 1996. For commercial snow blowers, the model uses the number of employees in landscaping and horticultural services, combined with snowfall, to allocate a state's snow blower population. For counties that did not receive at least 15 inches of snow in the 1996 Winter season (Dec., Jan.-Mar.), the allocation factors are set to zero so that no snow blowers are allocated to those counties. DNREC investigated the amount of snow that counties in Delaware received in 2002 (DSC, 2003). Snowfall amounts for the counties were: 9.5 inches in Kent County (one weather station); an average of 5.5 inches in New Castle County (four weather stations); and, an average of 4 inches in Sussex County (three weather stations). Thus, the snow blower allocation factors for all counties in Delaware were set to zero.

Recreational Equipment (except snowmobiles and golf carts)

DNREC contacted the Delaware Department of Transportation (DelDOT) Division of Motor Vehicles to determine whether registration data were available for off-road motorcycles and all-terrain vehicles (ATVs). Registration is required by the State of Delaware for these off-highway vehicles (OHVs). Snowmobiles are not included in the classification of OHVs. Table 4-8 presents the 2002 number of OHVs, registered for the State of Delaware, including off-road motorcycles and ATVs combined (Shock, 2003). In the NONROAD model, equipment populations of gasoline ATVs and off-road motorcycles total 13,024 for the State of Delaware.

Table 4-8. 2002 Off-Highway Vehicle Registrations

County	DelDOT OHV Registrations	NONROAD2002a Model Equipment Populations
Kent	38	0
New Castle	202	3,256
Sussex	6	9,768
State Total	**246**	**13,024**

Though significantly lower than the NONROAD model estimates, DelDOT indicated the registration data to be representative of OHV use in Delaware. Nonetheless, DNREC did not replace the NONROAD model estimates, obtained from the Motorcycle Industry Council, with populations based on DelDOT information.

Note that Kent County, which is less urbanized than New Castle County, is showing zero OHV populations in the NONROAD model. The NONROAD GAFs are based on 1996 County Business Patterns establishment data for SIC 7030 (Camp and Recreational Vehicle Parks). SIC 7030 is defined as "sporting and recreational camps providing lodging and meals, or lodging only. Included are children's camps, fishing camps, hunting camps, and dude ranches, and establishments providing overnight or short-term sites for recreational vehicles, trailers, campers, or tents." The County Business Patterns data showed no establishments in Kent County in 1996. In 2001, County Business Patterns data showed only one establishment in Kent County.

As an alternative to the NONROAD GAFs, new state-to-county GAFs were developed based on the amount of non-urbanized land area per county, presented in Table 4-7.

Snowmobiles

In the NONROAD model, snowmobile populations are allocated to counties with sufficient snowfall using a minimal average annual snowfall limit of 40 inches in 1996. For counties that did not receive at least forty inches of snow in the 1996 winter season, the allocation factors are set to zero so that no snowmobiles are allocated to those counties. Similar to snow blowers, the NONROAD model snowmobile allocation factors for all counties in Delaware are set to zero as a result of the 1996 data. Given the small amount of snow in Delaware for 2002, DNREC did not make changes to the NONROAD model inputs for this equipment category.

Golf Carts

To develop alternate county fractions for use in allocating state-level golf cart emissions to each county, GIS coverage was used for the land area of golf courses. See Table 4-7 for the county-specific values for golf course area in square kilometers. These data replaced the default surrogate data used in the NONROAD model, which represents the total number of golf courses per county.

Recreational Marine Equipment

DNREC investigated the availability of recreational boat registrations for the State of Delaware to obtain a more representative estimate of the total recreational marine equipment population in use for the State. Using boat registrations as a means to allocate recreational marine activity is likely to over or underestimate activity in specific counties because residents may register their boats in one county, but use their boats in other parts of the State or neighboring counties. The NONROAD model uses water surface area to apportion State recreational marine populations to counties, which is generally a suitable geographic allocation factor. DNREC believes that a disproportionately high fraction of pleasure craft activity is allocated to New Castle County. However, DNREC was unable to obtain data to adjust the allocation fraction for this county.

2002 in-state registrations of boats and personal watercraft for the State of Delaware were available from the Delaware Division of Fish and Wildlife (DNREC, 2003). Table 4-9 presents the 2002 boat registrations for the State of Delaware, as well as the equipment populations from the NONROAD model.

Table 4-9. 2002 In-State Boat Registrations and NONROAD Defaults

Vessel Type	Delaware In-State Registrations	NONROAD2002a Model
Inboard	5,729	14,517
Outboard	32,150	64, 916
In/Out (Inboard w/ stern drive)	6,315	
Jet Drive	4,860	
Other	509	
Personal Watercraft	5,239	8,765
Total	**54,802**	**88,198**

AQMS contacted the Delaware Division of Fish and Wildlife (DE F&W) to obtain clarification on the definitions and boat types included in “jet drive” and “other.” The “other” category includes non-power boats and electric trolling motors. The “jet drive” category refers to jet skis, which are already being accounted for in the personal watercraft registration data. As such, DNREC discounted vessel populations for these two categories in developing an estimate of revised Delaware state-level boat populations.

Next, the in-state registration data was augmented with estimates of the number of out-of-state boat ramp permits provided by DE F&W. Delaware F&W estimates that 1,500 boat ramp permits are issued each year. These out-of-state data are not reported by boat type; therefore, DNREC assumed the same distribution of boat types from the in-state data corresponding to vessels with a draft of 16 to 26 feet, since this is the most likely size category of boats coming from out of state (see Table 4-10).

Table 4-10. 2002 Out-of-State Boat Registrations

Vessel Type	In-State Registration Data (Vessels w/draft of 16 to 26 ft)	Ratio	Out-of-State Registration Data, Estimated by Vessel Type
Inboard	1,361	0.052	78
Outboard	19,933	0.758	1,136
In/Out	5,009	0.190	286
Total	**26,303**	**1.000**	**1,500**

DNREC also added the 2002 vessel registration data (497 total vessels) for commercial marine passenger (e.g., party boats) and fishing vessels into the NONROAD model population input files since these vessels are not included in the activity data used in the CMV category. The total vessel populations used in the NONROAD model for 2002 are provided in Table 4-11.

Table 4-11. 2002 Recreational Marine Equipment Populations

Vessel Type	Registration Data
Inboard + In/Out	12,905
Outboard	33,286
Personal Watercraft	5,239
Total	**51,430**

Delaware's registration data do not distinguish between gasoline and diesel-fueled engines for inboard/outboard vessels. DNREC estimated these engine counts using the fraction of gasoline versus diesel engines for total inboard/outboard engines as estimated from the NONROAD model. For commercial passenger and fishing vessels, populations were distributed to the 4-stroke gasoline and diesel inboard SCCs. This resulted in the following SCC level populations for Delaware:

Table 4-12. 2002 Recreational Marine Equipment Populations by SCC

SCC	Vessel Type	2002 Population
2282005015	Personal Watercraft	5,239
2282005010	2-Stroke Outboard	33,249
2282010005	4-Stroke Inboard + In/Out	12,010
2282020005	Diesel Inboard	895
2282020010	Diesel Outboard	37
Total		**51,430**

SCC-level populations were then allocated to horsepower ranges using the horsepower distribution within the NONROAD model. All commercial marine passenger and fishing vessels were assumed to be greater than 25 horsepower.

Aircraft Ground Support Equipment

In the NONROAD model, aircraft ground support equipment is allocated to counties using the number of employees in air transportation, as reported by the Census Bureau's *County Business Patterns*. However, this indicator may include employees that are not directly connected to aircraft operations. To allocate ground support equipment activity, the number of commercial aircraft landing and take-offs (LTOs) is believed to be a more appropriate surrogate, since the number of LTOs is a primary determinant of the level of aircraft ground support equipment activity at a given airport (EPA, 2002). The number of commercial aircraft LTOs for calendar year 2002 is presented in Table 4-19 within the aircraft category description. These data were incorporated into the GAF files for aircraft ground support equipment.

Logging Equipment

Per NONROAD model defaults (based on employment in the logging industry), no emissions would be reported in New Castle and Kent counties for the logging equipment category, which includes chain saws and shredders greater than six horsepower (hp), and fellers/bunchers/ skidders. Chain saws and shredders less than six hp are present in all counties and are accounted for in the lawn and garden equipment category. DNREC believes there is likely to be minimal to no commercial logging activity in New Castle County, but some activity for Kent County. DNREC contacted the Division of Forestry within the Department of Agriculture, and obtained data on the number of acres logged (Short, 2003). These data are shown in Table 4-7 and were used to refine the NONROAD model GAFs for distributing emissions to the three counties.

4.2.2 Non-road Refueling Emissions

The NONROAD model accounts for refueling emissions from non-road equipment for two separate components, vapor displacement and spillage. Non-road equipment may be fueled from a gasoline pump or a portable container. Delaware had a statewide Stage 2 program in place for 2002 (DNREC, 2002). Stage 2 non-road emissions are associated with non-road equipment being filled directly at the gasoline pumps. Portable fuel container (PFC) use results in vapor displacement and spillage emissions from refueling non-road equipment, as well as diurnal and permeation emissions resulting from storage. The PFC refueling emission component was estimated using fuel consumption for equipment filled using PFCs (typically smaller horsepower engines), obtained from the NONROAD model. While non-road related Stage 2 and PFC refueling emissions were included in the non-road source sector, emissions from the filling of PFCs at gasoline stations are accounted for in the gasoline marketing category within the non-point sector.

4.2.3 Emission Factors

The NONROAD model contains emission factor input files representing engine exhaust emissions rates and adjustments that are used to determine evaporative emissions. The pollutants addressed in the exhaust emission factor files include total hydrocarbons (THC), NO_x, and CO.

Emission factors are defined by SCC and power level range. Base, or uncontrolled, emission rates are specified and the effect of Federal non-road standards are reflected in technology type emission factors. All exhaust emission factors are expressed in units of grams per horsepower-hour (g/hp-hr) or grams per mile (g/mile). Evaporative THC emissions are based on fuel consumption. The model includes conversion factors by SCC to estimate VOC from THC.

4.2.4 Temporal Allocation

Table 4-13 summarizes the NONROAD model default seasonal activity allocation fractions for the Mid-Atlantic region by equipment category. Delaware is included in the Mid-Atlantic region.

Table 4-13. Default Seasonal Activity Allocation Fractions for the Mid-Atlantic Region in NONROAD

Equipment Category	Winter	Spring	Summer	Fall
Agricultural	0.060	0.270	0.400	0.270
Construction	0.150	0.234	0.381	0.234
Industrial	0.250	0.250	0.250	0.250
Lawn and Garden (excl. chainsaws)	0.060	0.270	0.400	0.270
Snow blowers/Snowmobiles	1.000	0.000	0.000	0.000
Commercial Marine	0.250	0.250	0.250	0.250
Airport Service	0.250	0.250	0.250	0.250
Logging (incl. chainsaws)	0.250	0.250	0.250	0.250
Light Commercial	0.250	0.250	0.250	0.250
Recreational Marine	0.021	0.204	0.570	0.204
Recreational Equipment	0.120	0.234	0.411	0.234
Railway Maintenance	0.250	0.250	0.250	0.250

Table 4-14 summarizes the model default weekday and weekend day activity allocation fractions by equipment category. SSWD values are based on the seasonal and weekly allocation fractions.

4.2.5 Controls

The NONROAD model is designed to account for the effect of federal emission standards. Table 4-15 provides a summary of the Federal emission standards affecting NONROAD model category engines, as well as the corresponding SCCs and engine size or horsepower.

In November 2002, a final rulemaking for large spark ignition (SI) engines (> 25hp) and recreational engines (both marine and land-based) was published. Since the implementation year for this rule is after 2002, these standards do not apply to this inventory.

In the NONROAD model, controlled emission rates are applied to new engines subject to Federal standards as they are phased-in over time. Rule penetration (RP) varies by SCC depending on the percentage of the population that is included in the horsepower range subject to the standard. Rule effectiveness (RE) is assumed to be 100 percent, since engine manufacturers are required to develop the technologies to meet these standards.

Table 4-14. Default Weekday and Weekend Day Activity Allocation Fractions in NONROAD[a]

Equipment Category	Weekday	Weekend Day
Recreational	0.1111111	0.2222222
Construction	0.1666667	0.0833334
Industrial	0.1666667	0.0833334
Residential Lawn and Garden	0.1111111	0.2222222
Commercial Lawn and Garden	0.1600000	0.1000000
Agricultural	0.1666667	0.0833334
Light Commercial	0.1666667	0.0833334
Logging	0.1666667	0.0833334
Airport Service	0.1428571	0.1428571
Railway Maintenance	0.1800000	0.0500000
Recreational Marine	0.0600000	0.3500000
Transportation A/C Refrigeration	0.1428571	0.1428571
Underground Mining	0.1666667	0.0833334
Oil Field Equipment	0.1428571	0.1428571

[a] The values are the fractions of weekly activity allocated to each weekday and each weekend day. To get the fraction for all weekdays, multiply the weekday fraction by 5. Similarly, to get the weekend fraction, multiply the weekend day fraction by 2.

Table 4-15. Summary of NONROAD Model Category Control Programs

Standard	SCC	Description	Applicable, HP
Phase I/II Small Spark-Ignition Handheld Engines	Specific applications of 2260	Gasoline Class III, IV, and V engines[a]	<25 hp
Phase I/II Small Spark-Ignition Non-handheld Engines	Specific applications of 2265	Gasoline Class I and II engines[a]	<25 hp
Tier 1/Tier 2 Large Spark-Ignition	2260xxxxxx 2265xxxxxx 2267xxxxxx 2268xxxxxx	2-stroke gasoline 4-stroke gasoline Liquefied petroleum gasoline (LPG) Compressed natural gasoline (CNG)	>=25 hp
Recreational Vehicles	2260001010 2265001010	Gasoline Off-highway Motorcycles	All hp
Recreational Vehicles	2260001020 2265001020	Gasoline Snowmobiles	All hp
Recreational Vehicles	2260001030 2265001030	Gasoline ATVs	All hp
Recreational Marine Exhaust Emission Standards	2282005xxx 2282010xxx	Gasoline Pleasure Craft - Outboard, Personal Watercraft, and Inboard	All hp
Evaporative Emission Standards (Proposed)	2282005xxx 2282010xxx	Gasoline Pleasure Craft - Outboard, Personal Watercraft, and Inboard	All hp
Tier 1/2/3 Compression-Ignition	2270xxxxxx	Diesel Equipment	All hp
Tier 1/2 Compression-Ignition	2282020xxx	Diesel Pleasure Craft	<50 hp
Diesel Recreational Marine	2282020xxx	Diesel Pleasure Craft	>50 hp

[a] EPA established technology classes based on use (hand-held versus non-handheld and displacement) that are predominately 2-stroke (Class III, IV, and V), or 4-stroke (Class I and II) engines.

4.2.6 Sample Calculations and Results

The standard NONROAD model emission equation is as follows:

$$I_{exh} = E_{exh} * A * L * P * N$$

where:
- I_{exh} = Exhaust emissions, (ton/year)
- E_{exh} = Exhaust emission factor, (ton/hp-hr)
- A = Equipment activity, (hours/year)
- L = Load factor, (proportion of rated power used on average basis)
- P = Average rated power for modeled engines, (hp)
- N = Equipment population

Table 4-16. 2002 Statewide Annual and SSWD VOC, NO_x, and CO Emissions for NONROAD Equipment

		Annual (TPY)			SSWD (TPD)		
Fuel Type	**Equipment Category**	**VOC**	**NO_x**	**CO**	**VOC**	**NO_x**	**CO**
Gasoline	Recreational	612	23	2,883	2.12	0.07	10.17
	Construction	166	24	2,063	0.62	0.08	7.92
	Industrial	58	54	1,347	0.18	0.14	4.43
	Lawn & Garden	2,805	330	36,235	11.44	1.27	161.83
	Agriculture	18	8	389	0.09	0.04	2.03
	Light Commercial	413	96	9311	1.38	0.25	30.65
	Logging	3	< 1	22	0.01	< 0.01	0.07
	Airport Support	< 1	< 1	5	< 0.01	< 0.01	0.01
	Railway Maintenance	1	< 1	17	< 0.01	< 0.01	0.06
	Recreational Marine	2,726	201	7,433	6.75	0.48	19.19
Diesel	Recreational	1	3	4	< 0.01	0.01	0.01
	Construction	279	2,415	1,351	1.04	9.03	5.05
	Industrial	44	403	188	0.13	1.23	0.57
	Lawn & Garden	16	108	57	0.08	0.53	0.28
	Agriculture	101	828	482	0.51	4.21	2.45
	Light Commercial	29	167	107	0.09	0.48	0.34
	Logging	< 1	6	2	< 0.01	0.02	0.01
	Airport Support	1	8	4	< 0.01	0.02	0.01
	Railway Maintenance	2	8	7	0.01	0.03	0.02
	Recreational Marine	4	108	17	0.01	0.28	0.04
LPG	All Equipment	249	920	3,678	0.80	2.95	11.80
CNG	All Equipment	1	87	352	< 0.01	0.28	1.13
All Fuels	**Total**	**7,531**	**5,798**	**65,954**	**25.28**	**21.40**	**258.10**

4.2.7 References

BOC, 2003: U.S. Department of Commerce, Bureau of the Census, *2000 County and State Housing Units by Unit Type, Census 2000*. At (http://factfinder.census.gov/servlet/DTTable?_ts=84275328235)

DNREC, 2002: Delaware Department of Natural Resources and Environmental Control, *Regulation No. 24, Control Of Volatile Organic Compound Emissions, Section 36 – Stage II Vapor Recovery*. January 11, 2002.

DNREC, 2003: Delaware Department of Natural Resources and Environmental Control, Division of Fish and Wildlife, *Delaware Annual Boating Statistics.* At (http://www.dnrec.state.de.us/fw/boatstats.htm)

DSC, 2003: Delaware State Climatologist, University of Delaware, *Monthly Climate Data- Monthly Snowfall*, at (http://www.udel.edu/leathers/monthly.html)

EPA, 2002: U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Office of Air and Radiation, *Geographic Allocation of State Nonroad* Engine Population Data to the County Level, EPA-420-P-02-009, July 2002.

EPA, 2003: U.S. Environmental Protection Agency, Office of Transportation and Air Quality, *Draft NONROAD2002a*, [Computer software], June 2003.

EPA, 2005: U.S. Environmental Protection Agency, Office of Transportation and Air Quality, *NONROAD2005*, [Computer software], December 2005.

NCDC, 2003: National Climatic Data Center, Data Set 9956 (DSI-9956), Datsav3 Global Surface Hourly Data, Asheville, NC 28801, January 6, 2003.

Shock, 2003: K. Shock, Delaware Department of Transportation, Division of Motor Vehicles, personal communication, via email, with M. Spivey, E.H. Pechan & Associates, Inc., October 2003.

Short, 2003: Austin Short, Delaware Department of Agriculture, personal communication, via email, with D. Fees, Delaware Department of Natural Resources and Environmental Control, Air Quality Management Section, December 2, 2003.

4.3 Aircraft

The aircraft source category includes emissions from commercial, air taxi, general aviation, and military aircraft. These sub-categories are described as follows:

- Commercial aircraft are used for scheduled service transporting passengers, freight, or both;
- Air taxis are used for scheduled service carrying passengers and/or freight, but are smaller aircraft that operate on a more limited basis than the commercial carriers;
- General aviation includes other non-military aircraft used for recreational flying, business, personal transportation, and various other activities; and
- Military aircraft are used by the U.S. military in a wide range of missions.

Airport-specific emissions for all aircraft sub-categories were allocated to the county in which each airport is located. Where there are multiple airports in a given county, the emissions were summed to provide a county-level emissions estimate. Aircraft emissions are reported under the following SCCs:

Table 4-17. SCCs for Aircraft

SCC	Descriptor 1	Descriptor 3	Descriptor 6	Descriptor 8
2275001000	Mobile Sources	Aircraft	Military Aircraft	Total
2275020000	Mobile Sources	Aircraft	Commercial Aircraft	Total: All Types
2275050000	Mobile Sources	Aircraft	General Aviation	Total
2275060000	Mobile Sources	Aircraft	Air Taxi	Total

4.3.1 Activity Data

DNREC estimated annual aircraft emissions using a combination of airport-specific activity data and Federal Aviation Administration (FAA)/EPA emission factors. Estimating aircraft emissions focuses on the “mixing zone,” which has a height (mixing height) equal to the thickness of the inversion layer. Air emissions within this zone are trapped by the inversion layer and ultimately affect ground-level pollutant concentrations. When aircraft are above the mixing zone, emissions tend to disperse and have no ground-level effects. The aircraft operations within the mixing zone are defined by the landing and take-off (LTO) cycle. Each LTO cycle consists of five specific operating modes:

- Approach – aircraft operates in this mode when it approaches the airport on its descent from the mixing height to when it lands on the runway.
- Taxi/idle-in – aircraft operates in this mode when it taxis from the runway to the gate and turns its engines off.
- Taxi/idle-out – this period occurs from engine start-up to take-off as the aircraft taxis from the gate back out to the runway.
- Take-off – this mode is characterized primarily by full-throttle operation that typically lasts until the aircraft reaches between 500 and 1000 feet above ground, which is when engine power is reduced.

- Climb-out – this mode begins right after the take-off mode and lasts until the aircraft passes out of the mixing height.

The operation time in each of these modes is dependent on the aircraft category, local meteorological conditions, and operational considerations at a given airport. The time-in-mode (TIM) for the take-off operating mode is the least variable.

The following are the general steps to be used to estimate aircraft emissions:

- Determine the mixing height to be used to define the LTO cycle;
- Define the fleet make-up for each airport;
- Determine airport activity in terms of the number of LTOs by aircraft/engine type;
- Select emission factors for each engine model associated with the aircraft fleet;
- Estimate the TIM for the aircraft fleet at each airport;
- Calculate emissions based on aircraft LTOs, emission factors for each aircraft engine model, and estimated aircraft TIM;
- Aggregate the emissions across aircraft; and
- Convert hydrocarbon (HC) emissions to VOC emissions.

Commercial Aircraft

DNREC first contacted the Delaware Aeronautics Administration (DAA), to obtain LTOs for Delaware airports (VanDenHeuvel, 2004). Because the data from DAA were not reported by aircraft or engine type, DNREC made a written request of additional data needed to the individual airports. DNREC contacted New Castle County Airport, Sussex County Airport, and Dover Air Force Base to request the number of U.S. commercial aircraft LTOs by aircraft/engine model for calendar year 2002, as well as TIM data specific to each airport. Table 4-18 presents the commercial aircraft LTO data obtained by aircraft and engine type

Table 4-18. 2002 Commercial Aircraft LTO Data

Make of Aircraft	Engine Type	No. of Engines	LTOs
New Castle County Airport			
DC-8-50F (DC8-50F)	JT3D3-3B (JT3D-3B)	4	8
DC-9-15F (DC9-15F)	JT8D-7B	2	10
DC-9-30 (DC9-30)	JT8D-7B	2	3
B-727-200 (B727-200)	JT8D-15	3	3
B-737-300 (B737-300)	CF56-3 (CFM56-3)	2	2
B-757-200 (B757-200)	RB211-535C	2	2
FALCON 20C (Falcon 20)	CF700-2D2 (CF700-2D)	2	13
FALCON 900B (Falcon 100)	TFE731-3	3	5
Dover AFB			
Gulf Stream 5	RR BR710-48 (BR700-710A1-10 GulfV)	2	580
H/B-747 (B747-400)	GE or PW (PW4056)	4	1,449
H/MD-11(MD-11)	GE or PW (PW4460)	4	290

DNREC used these airport-specific LTO data to estimate commercial aircraft emissions using FAA's Emissions and Dispersion Modeling System (EDMS), Version 4.12 (FAA, 2003). The model requires detailed inputs on aircraft operation by aircraft and engine type. DNREC matched the aircraft LTO data to the existing aircraft/engine types in EDMS, and used the default EDMS TIM data. A mixing height of 2,300 feet was used for all airports in Delaware based on an isopleth chart of annual average morning mixing heights for the continental U.S. as provided in EPA's *Procedures* Manual (EPA, 1992). Table 4-18 presents the aircraft/engine assignments made for EDMS.

EDMS generates emissions for HC, NO_x, and CO, in tons per year. The model also generates emissions for ground support equipment (GSE). However, the GSE estimates generated from the NONROAD model were used for the 2002 inventory, so these were subtracted from the EDMS results.

Air Taxi and General Aviation

DNREC contacted the following airports to request the number of 2002 LTO for the air taxi and general aviation sub-categories, as well as TIM data:

Kent County:
- Chandelle Estates
- Chorman
- Delaware Airpark
- Dover AFB
- Henderson
- Jenkins
- Smyrna

New Castle County:
- New Castle County
- Summit

Sussex County:
- Laurel
- Sussex County Airport

The activity data collected for these airports/aircraft types, presented in Table 4-19, represents total LTOs. In a few cases, data by aircraft type were provided (e.g., Sussex County Airport), but the data were too general to match to existing aircraft types in EDMS. As such, EPA fleet average emission factors were applied to the LTO data to estimate annual general aviation and air taxi emissions (EPA, 1992).

Military Aircraft

DNREC estimated military aircraft emissions using the same methods as the commercial aircraft sub-category (i.e., FAA's EDMS). Dover Air Force Base (AFB) and New Castle County Airport are the only airports in Delaware known to have military operations. The Delaware Army National Guard (DE ARNG) and the Delaware Air National Guard (DE ANG) operate units at the New Castle County Airport. DNREC contacted these airports to obtain airport-specific LTO and fleet mix data for calendar year 2002. DNREC obtained fleet mix data for military operations at Dover AFB, and estimated fleet mix data for military operations at New Castle County airport based on their 1999 fleet mix, since they provided only the total military LTOs (DNREC, 2002).

Table 4-19. 2002 General Aviation and Air Taxi LTO Data

Airport	County	Category	LTOs
Smyrna	Kent	General Aviation	1,263
Jenkins	Kent	General Aviation	1,250
Henderson	Kent	General Aviation	900
Chandelle Estates	Kent	General Aviation	3,400
Delaware Airpark	Kent	General Aviation	18,000
Dover AFB	Kent	General Aviation	1,967
Chorman	Kent	General Aviation	840
New Castle County	New Castle	General Aviation	56,458
New Castle County	New Castle	Air Taxi	1,941
Summit	New Castle	General Aviation	41,644
Sussex County	Sussex	General Aviation	14,960
Laurel	Sussex	General Aviation	3,875

Dover AFB and DE ANG operate low-level training flights termed “touch and gos” (TGs). TGs are flights conducted mostly below the mixing height, with different engine power settings and emissions rates than LTOs. When entering airport fleet mix data into EDMS, DNREC accounted for the percentage of annual LTO categorized as TG operations for Dover AFB. “Touch and go” operations were not obtained for the DE ANG. Refer to Table 4-20 for a summary of annual LTO and TG operations data for military aircraft.

Table 4-20. 2002 Military Aircraft LTO Data

Make of Aircraft	Engine Type	No. of Engines	LTOs	TGs
Dover AFB				
C-5 Galaxy	GE TF-39 (TF39-GE-1)	4	6,346	14,806
C-130	T56-15	4	261	608
C-17 (C-17A)	F117-PW100	4	435	1,014
C-141	GTCP 165-1 (used TF33-P-7)	4	261	608
KC-10 (KC-10A)	F103-101 (F103-GE-100_101)	3	261	608
KC-135 (KC-135R)	F108-100 (F108-CF-100)	4	174	406
A-10 (A-10A Thunderbolt)	T34-GE-100 (TF34-GE-100-100A)	2	174	406
F-16	F100-PW-220	1	87	203
New Castle County Airport[a]				
C-130	T56-A-16	4	2,066	NA
BEECH C-12 (C-12A/B/C)	PT6A-42	2	131	NA
C-9 (C-9A or C-9B)	JT8D-9	2	1,158	NA
C-130	T56-A-15	5	127	NA
VC-137 (B-707-E)	CFM56-2B-1	4	114	NA
Grumman Gulfstream (Gulfstream I)	Dart RDa7 (RDa7)	2	1,012	NA

[a]Aircraft LTO distribution for 2002 estimated by applying 1999 fraction of total LTOs by aircraft type to 2002 reported LTOs.

4.3.2 Emission Factors

Emission factors for all aircraft categories were obtained from either EPA's *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emissions Inventory* (EPA, 2002), or EDMS. Table 4-21 lists the fleet average emission factors by aircraft SCC. Conversion factors obtained from EPA documentation were applied to the HC emission estimates to obtain VOC emissions. Table 4-22 lists the VOC/HC conversion factors by aircraft category.

Table 4-21. Fleet Average Emission Factors by Aircraft SCCs

		Emission Factors lbs/LTO		
SCC	**Aircraft Category**	**VOC**	**NO_x**	**CO**
2275050000	General Aviation	0.3825	0.065	12.014
2275060000	Air Taxi	1.2234	0.158	28.13

Table 4-22. Aircraft VOC to HC Conversion Factors

Aircraft Category	VOC/HC Conversion Factors
Commercial	1.0947
General Aviation	0.9708
Air Taxi	0.9914
Military	1.1046

4.3.3 Temporal Allocation

DNREC obtained monthly operations data from the Dover AFB (military and commercial), Summit Airport, and Sussex County Airport. These monthly data were used to develop airport-specific monthly allocation profiles. The monthly profile from the Dover AFB (representing both military and commercial LTOs) was considered representative of the seasonality of activity from the commercial and military sectors. Therefore, the monthly profile was applied to the military, commercial, and air taxi annual LTOs reported by the New Castle County Airport. The monthly profile from the Summit Airport for general aviation was considered representative of the seasonality of activity from airports with more than 20,000 LTOs annually. This profile was applied to the general aviation annual LTOs reported by the New Castle County Airport. Finally, the monthly profile from the Sussex County Airport was used to represent seasonality associated with smaller airports (less than 20,000 LTOs annually.) This monthly profile was applied to all general aviation annual LTOs reported by Kent and Sussex County airports.

To estimate commercial and air taxi aircraft typical summer weekday emissions, DNREC assumed that activity occurs primarily during the weekdays (e.g., 90 percent of total weekly activity), based on the assumption that the majority of commercial flights are scheduled during weekdays. For general aviation and military aircraft, weekday emissions were estimated using an operating schedule of seven days per week.

4.3.4 Controls

EDMS represents current actual emission rates and as such additional controls were not applied to emissions calculated using EDMS. Fleet average emission factors represent older emission rate data, and are likely uncontrolled. However, information on emission reductions related to the aircraft engine standards established by the International Civil Aviation Organization (ICAO) were determined not to be available, and the reductions are believed to be minimal.

4.3.5 Sample Calculations and Results

Commercial and Military Aircraft

The equation below is the calculation of taxi and queue mode time that is an airport-specific input in EDMS.

Taxi and Queue Mode Time = (Airport Average Taxi-In Time + Airport Average Taxi-Out Time) - EDMS Aircraft-Specific Landing Roll Time

The following is the equation used in EDMS to calculate annual emissions by aircraft type for one LTO cycle (FAA, 2002):

$$E_{ij} = \Sigma\, [(TIM_{jk}) * (FF_{jk}/1000) * (EI_{ijk}) * (NE_j)]$$

where:

- E_{ij} = Total emission of pollutant *i*, in pounds, produced by aircraft type *j* for one LTO cycle.
- TIM_{jk} = Time in mode for mode *k*, in minutes, for aircraft type *j*
- FF_{jk} = Fuel flow for mode *k*, in pounds per minute, for each engine used on the aircraft type *j*
- EI_{ijk} = Emission index for pollutant *i*, in pounds of pollutant per one thousand pounds of fuel, in mode *k* for aircraft type *j*
- NE_j = Number of engines used on aircraft type *j*

Finally, annual emissions per airport are calculated with the following equation:

$$\text{Annual Emissions for Airport A (tons/yr)} = \Sigma\, [(E_{ij} * LTO_j)]/2000 \text{ lbs/ton}$$

where:

- $E_{i,j}$ = annual emissions in pounds of pollutant *i*, produced by aircraft type *j* per LTO cycle.
- $LTOs_j$ = annual number of LTOs for aircraft type j

Air Taxi and General Aviation Aircraft

The following equation is the estimate of air taxi and general aviation aircraft emissions using LTO data and fleet average emission factors.

$$E_i = LTOs \times EF_i \times {}^{1}\!/_{2000}$$

where:

E_i = annual emissions in tons of pollutant *i*
LTOs = annual number of LTOs
EF_i = default aviation fleet mix emission factor in pounds of pollutant for pollutant *i*

Table 4-23. 2002 Statewide Annual and SSWD VOC, NO_X, and CO Emissions for Aircraft

SCC	Aircraft Category	Annual (TPY)			SSWD (TPD)		
		VOC	NO_X	CO	VOC	NO_X	CO
2275001000	Military	256	880	612	0.82	2.82	1.96
2275020000	Commercial	6	85	62	0.03	0.34	0.25
2275050000	General Aviation	28	5	868	0.09	0.02	2.78
2275060000	Air Taxi	1	< 1	27	< 0.01	< 0.01	0.11
22750xxxxx	**Total: Aircraft**	**291**	**970**	**1570**	**0.94**	**3.18**	**5.11**

4.3.6 References

DNREC, 2002: Delaware Department of Natural Resources and Environmental Control, Division of Air and Waste Management, Air Quality Management Section, *1999 Periodic Ozone State Implementation Plan Emissions Inventory for VOC, NO_x and CO*, 2002.

EPA, 1992: U.S. Environmental Protection Agency, Office of Air and Radiation, *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, EPA-450/4-81-026d (Revised), 1992.

EPA, 2002: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emissions Inventory, Volume I: Methodology*, prepared by Eastern Research Group, Morrisville, NC for the U.S. Environmental Protection Agency, November 2002.

FAA, 2003: Federal Highway Administration, “Emissions and Dispersion Modeling System (EDMS) Version 4.12,” October 2002.

VanDenHeuvel, 2004: H. VanDenHeuvel, Delaware Department of Transportation, personal communication, via email, with M. Spivey, E.H. Pechan & Associates, Inc., January 31, 2004.

4.4 Locomotives

Railroad locomotives are a combustion source of emissions with most significant emissions occurring where there is a concentration of railroad activity (such as a large switch yard). The primary fuel consumed by railroad locomotives is distillate oil (diesel fuel). Locomotives can perform two different types of operations: line haul and yard (or switch). Line haul locomotives generally travel between distant locations, such as from one city to another. Yard locomotives are primarily responsible for moving railcars within a particular railway yard. Locomotive emissions are reported under the following SCCs:

Table 4-24. SCCs for Locomotives

SCC	Descriptor 1	Descriptor 3	Descriptor 6	Descriptor 8
2285002006	Mobile Sources	Railroad Equipment	Diesel	Line Haul Locomotives: Class I Operations
2285002007	Mobile Sources	Railroad Equipment	Diesel	Line Haul Locomotives: Class II/Class III Operations
2285002010	Mobile Sources	Railroad Equipment	Diesel	Yard Locomotives

4.4.1 Activity Data

For line haul locomotives, DNREC calculated Class I operation emissions separately from Class II/III operations. Line haul locomotive emissions for passenger trains and commuter lines were estimated to be zero since rail service in Delaware (Amtrak and SEPTA) is electric powered. Fuel consumption was used to estimate locomotive engine emissions. Fuel consumption rates are usually known only for the entire interstate operating region, therefore, it is necessary to allocate the total amount of fuel consumed "system-wide" to Delaware.

Line Haul Locomotives – Class I Operations

Norfolk Southern and CSX Transportation operate Class I locomotives within Delaware. DNREC contacted these companies to obtain estimates of fuel consumption or data to calculate fuel consumption (e.g., gross ton-miles (GTM) and gallons of fuel consumed per GTM).

Norfolk Southern and CSX provided to DNREC GTM data at the county level for each county in Delaware in which they operated. Norfolk Southern provided a fuel consumption index (GMT/fuel consumed) for the system that includes operations in Delaware. CSX provided system-wide GMT and fuel consumption, from which a system-wide fuel consumption index (FCI) was calculated. CSX only operates in New Castle County. County-level GMT was divided by the fuel consumption index to estimate county-level fuel consumption. The system-wide fuel consumption indices, county-specific GMT, and calculated county-level uel consumption are provided in Table 4-25.

Line Haul Locomotives – Class II/III Operations

The Brandywine Valley Railroad, Maryland & Delaware Railroad, and the Delaware Coast Line Railroad operate Class II/III locomotives within Delaware. These companies were contacted to obtain estimates of fuel consumption. All three railroads provided 2002 statewide fuel consumption data. Since the Brandywine Valley Railroad only operates in New Castle County, and the Delaware Coast Line Railroad only operates in Sussex County, the fuel data are county specific. The Maryland & Delaware Railroad operates in New Castle and Sussex Counties. Track miles within each county were used to allocate statewide fuel consumption to each county. Table 4-26 presents a summary of the activity data calculated by Class II/III railroad and county for 2002.

Table 4-25. 2002 Locomotive Fuel Consumption Data for Class I Line Haul Operations

Class I Railroad	County	Gross Ton Miles (GMT)	System-wide GMT/Gallon Diesel	Fuel Consumed, gallons/year
Norfolk Southern	Kent	231,873,699	790.03	293,500
Norfolk Southern	New Castle	322,158,680	790.03	407,780
Norfolk Southern	Sussex	141,653,747	790.03	179,302
CSX Transportation	New Castle	736,781,000	908.87	810,654

Table 4-26. 2002 Locomotive Fuel Consumption Data for Class II/III Line Haul Operations

Class II/III Railroad	County	Fuel Consumed, gallons/year
Brandywine Valley	New Castle	15,600
Maryland & Delaware	New Castle	1,719
Maryland & Delaware	Sussex	2,306
Delaware Coast Line	Sussex	9,730

Yard Locomotives

Norfolk Southern and CSX Transportation have yard operations within Delaware. These companies provided the number of locomotives by switchyard location. CSX only operates a switchyard in New Castle County. For each company, the number of locomotives was summed by county. Table 4-27 provides a summary of switchyard operations and fuel consumption by county. An average switchyard engine fuel consumption estimate of 82,490 gallons per year was applied (EPA, 1992). The EPA estimate assumes switchyard locomotive operations running 24 hours per day, 365 days per year.

Table 4-27. 2002 Switchyard Activity and Estimated Fuel Consumption

Class I Switchyard	County	No. of Yard Locomotives	Fuel Consumed, gallons/year[a]
Norfolk Southern	Kent	4	329,960
Norfolk Southern	New Castle	9	742,410
Norfolk Southern	Sussex	2	164,980
CSX Transportation	New Castle	5	412,450

[a]Estimated assuming 82,490 gallons fuel consumed per yard locomotive.

4.4.2 Emission Factors

Emission factors for line haul and yard locomotives were obtained from Table C-1 of Appendix C in *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emissions Inventory* (EPA, 2002). Emission factors are expressed in grams per gallon. See Table 4-28 for the emission factors used.

Table 4-28. Emission Factors for Locomotives

Pollutant	Line Haul Emission Factor, grams/gallon	Switchyard Emission Factor, grams/gallon
VOC	10.05	21.105
NO_x	270	362
CO	26.6	38.1

4.4.3 Temporal Allocation

Emissions from this source category are not expected to vary substantially from season to season. Uniform monthly temporal allocation was assumed. To estimate typical summer weekday emissions, DNREC assumed that locomotive operate evenly 7 days a week.

4.4.4 Controls

In the Regulatory Support Document (RSD) for locomotive emission standards, national emissions account for future, phased-in controls that will reduce NO_x, particulate and hydrocarbon emissions (EPA, 1997). Emission reductions, which include RE and RP, are estimated based on the percent change in emissions from the base year to a given projection year. The 2002 Class I line haul and yard locomotive emissions for NO_x were reduced by the percentages shown in Table 4-29. For the Class II/III locomotives, emissions were estimated as uncontrolled since the RSD standards do not take effect until 2003.

Table 4-29. Percent Reduction Applied to Locomotive NO_x Emissions

Source Category	Percent Reduction
Class I Line Haul Locomotive	12
Yard Locomotive	2

4.4.5 Sample Calculations and Results

Line Haul Locomotive

To determine the amount of pollutant ***p*** at the county level:

$$E_{px} = FC \times EF_p \times \frac{1}{2000}$$

where: E_p = amount of pollutant ***p*** emitted for the county in pounds
FC = fuel consumption for the county in gallons

EF_p = emission factor for pollutant ***p*** in pounds per gallon

Yard Locomotive

To determine the amount of pollutant ***p*** at the county-level:

$$E_p = Yd * FC_{Yd} * EF_{\boldsymbol{p}}$$

where: E_p = amount of pollutant ***p*** emitted for the county in pounds
Yd = number of yard locomotives in the county
FC_{Yd} = fuel consumption per yard locomotive in gallons per year
EF_p = emission factor for pollutant ***p*** in pounds per gallon

Table 4-30. 2002 Statewide Annual and SSWD VOC, NO_x, and CO Emissions for Locomotives

SCC	Category Description	Annual (TPY)			SSWD (TPD)		
		VOC	NO_X	CO	VOC	NO_X	CO
2285002006	Class I Line Haul	19	443	50	0.05	1.22	0.14
2285002007	Class II/III Line Haul	< 1	9	1	< 0.01	0.02	< 0.01
2285002010	Yard Locomotives	38	645	69	0.11	1.77	0.19
22850020xx	**Total: Locomotives**	**57**	**1,097**	**120**	**0.16**	**3.02**	**0.33**

4.4.6 References

EPA, 1992: U.S. Environmental Protection Agency, Office of Air and Radiation, *Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources*, EPA-450/4-81-026d (Revised), 1992.

EPA, 1997: U.S. Environmental Protection Agency, Office of Mobile Sources, *Locomotive Emission Standards: Regulatory Support Document*, December 1997.

EPA, 2002: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emissions Inventory, Volume I: Methodology*, prepared by Eastern Research Group, Morrisville, NC for U.S. EPA, November 2002.

4.5 Commercial Marine Vessels (Exhaust Emissions)

The CMV sector includes many types of vessels, such as large deep draft vessels, barge towboats, harbor tugs, dredging vessels, ferries, excursion vessels, and commercial fishing vessels. In addition to the numerous vessel types, each vessel type engages in different activities such as hotelling, maneuvering within the port, and cruising.

In its 1999 final rule for commercial marine diesel engines, EPA defined three categories of marine diesel engines based on engine displacement, power and revolutions per minute (rpm) (EPA, 1999a). Table 4-31 presents the definitions for each category. The EPA developed a baseline emissions inventory for each category. In 2003, a separate rule was finalized for Category 3 engines. EPA prepared a more detailed emissions inventory for Category 3 engines in the regulatory support document for that rulemaking (EPA, 2003).

Table 4-31. U.S. EPA Marine Engine Category Definitions

Category	Displacement per cylinder	Power range (kW)	RPM range
1	disp. < 5 liters and power $\geq$ 37 kW	37 - 2,300	1,800 - 3,000
2	5 $\leq$ displacement < 30 liters	1,500 - 8,000	750 - 1,500
3	displacement $\geq$ 30 liters	2,500 - 80,000	60 - 900

The EPA classifies CMV emissions by fuel type (residual and diesel) and by either vessel type (ocean-going, harbor, fishing, and military) or mode of operation (port and underway). DNREC used the port and underway SCCs to characterize the CMV emissions as listed below.

Table 4-32. SCCs for Commercial Marine Vessels

SCC	Descriptor 1	Descriptor 3	Descriptor 6	Descriptor 8
2280002100	Mobile Sources	Marine Vessels, Commercial	Diesel	Port emissions
2280002200	Mobile Sources	Marine Vessels, Commercial	Diesel	Underway emissions
2280003100	Mobile Sources	Marine Vessels, Commercial	Residual	Port emissions
2280003200	Mobile Sources	Marine Vessels, Commercial	Residual	Underway emissions

CMVs often burn multiple types of fuel and may burn different fuels for different operating modes or locations (i.e., near ports). The SCC classification is based on the most common type of fuel utilized by the vessel category. Ocean-going vessels (OGV) predominately burn intermediate fuel oil (IFO). DNREC placed emissions from OGV burning IFO in the residual fuel SCC. This is consistent with how petroleum product sales data are reported by the Energy Information Administration and EPA's classification of fuels (EPA 1999b).

There are four activity modes for CMV; cruise, reduced speed zone (RSZ), maneuver, and hotel. Underway emissions are estimated as the combined activity of cruise and RSZ modes. Port emissions are estimated as the combined activity of maneuvering and hotelling modes. Emissions from ferries and dredging are considered port emissions since these vessels operate primarily within the port area.

DNREC calculated emissions for ocean-going vessels, towboats, tug-assist vessels, ferries and vessels associated with dredging operations. Sample calculations are included throughout this section due to the complexity of this category. Details of the estimation methodology can be found in the spreadsheets and databases that accompany this report.

4.5.1 Activity Data

CMV engine emissions are assumed to be a function of the following:

- Mode of operation,
- Vessel type (bulk carrier, tanker, towboat, etc.);
- Vessel dead weight tonnage (DWT);
- Type of engine (2-stroke, 4-stroke, or steam); and
- Length of waterway segment.

Therefore, DNREC accounted for these variations when estimating CMV activity. The four modes of operation that are performed by vessels are defined below:

Cruise - This mode is assumed to begin 25 miles out from the port breakwater until the vessel reaches the breakwater (EPA, 1999c). The breakwater is located at the mouth of the Delaware Bay. Although Delaware's jurisdictional waters extend only three miles beyond the coastline, emissions were calculated based on the 25 miles beyond breakwater to account for vessels cruising just off the coast and for emissions beyond three miles that may impact Delaware's air quality.

Reduced Speed Zone (RSZ) - This mode begins at the breakwater and continues until the vessel is one to two nautical miles from the berth or anchorage. The vessel is assumed to have a speed of ten knots during this mode (EPA, 1999c). This mode is also referred to as transit and escort for towboats and tug-assist vessels.

Maneuvering - This mode is defined as the time the vessel slows to below four knots until the dock lines are secure. This mode is also referred to as assist mode for tug-assist vessels.

Hotelling - This mode is defined as the time the vessel is at dock. During this mode, the vessel operates auxiliary engines for electrical power.

The waterway segment distances used to estimate activity and to allocate the activity to the county level are given in Table 4-33 (DNREC, 2002; USACE, 2001). The distance South is given to the breakwater. The distance north is given to the Delaware-Pennsylvania border. The distance for the C&D Canal East is given from the Delaware-Maryland border to the entrance of the Delaware River (Reedy Point). The location of the Premcor Refinery is shown as south relative to the C&D canal, when it is actually just north of the canal. The distances were obtained from two different sources, hence the discrepancy, but future inventories will reflect the accurate relative location.

The engine activity for each mode is calculated using the following equation:

$$Activity_{mode} = Power \times LoadFactor \times Time_{mode} \times Calls$$

where:

$Activity_{mode}$	=	activity by mode (kilowatt-hours)
Power	=	rated engine power by vessel and engine type (kilowatts)
Load Factor	=	load factor of the engine by vessel type and mode
Time	=	time in mode per call by vessel type (hours)
Calls	=	number of calls by vessel and engine type

This calculation must be performed for both propulsion and auxiliary engines and for each mode. Both propulsion engines and auxiliary engines are operating during cruise, RSZ and maneuvering modes. Only auxiliary engines operate during hotelling. Once the activity is calculated, it is allocated to the county level using county allocation factors.

This approach to calculating activity of CMVs was used for all vessel types except vessels involved in dredging activity. For dredging, the activity data used for emissions calculations was the volume of material dredged. Details on the sources and development of activity data are given in the following subsections.

Table 4-33. Waterway Segment Distances for the Delaware River Area

Waterway Segment	Distance (mi.)
Point	**South**
DE/PA Border	83.1
Port of Wilmington	76.5
Delaware Terminal	75.0
Oceanport	69.0
C&D Canal	62.5
Premcor Refinery	62.1
Latitude 39°30'	57.6
New Castle Co/Kent Co	48.6
Kent Co/Sussex Co	15.8
Point	**North**
Port of Wilmington	6.6
C&D Canal	20.6
Point	**East**
C&D Canal	12.9

Ocean-Going Vessels

DNREC obtained vessel call data for ocean-going vessels (OGVs) during calendar year 2002 from the Marine Exchange of the Delaware River (ME, 2004). Data were obtained for vessels that called on ports in Delaware, New Jersey and Pennsylvania. The data for the entire port area is required since the majority of the vessels pass through Delaware waterways en route to other ports. The vessel call data included the vessel name, ship type (i.e., container, bulk carrier, tanker), DWT, pier, and the date of the call.

Vessels may shift between piers during the same call on the Delaware River Area. DNREC adjusted the vessel call data to remove shifts between piers, where possible, to avoid double counting using a methodology recommended by the staff of the Marine Exchange of the Delaware River. Data on the engine power and engine type (2-stroke, 4-stroke, and steam) used on OGVs were not available through the Marine Exchange. Therefore, DNREC assigned engine power and engine type based on average engine data obtained from other sources.

Auxiliary engine power is typically reported as total installed power, not as power for each engine. For the Houston-Galveston emissions inventory, a study on OGV auxiliary engine power and load factors for hotelling was conducted (HARC, 2000). The average engine power and load factor was given by vessel type. No size was reported for refrigerated container vessels (reefers) in this report. Auxiliary engines for reefers are generally large; therefore, DNREC assumed these engines were 6,000 kW operating at a load factor of 50% (EPA, 2001). Table 4-34 summarizes the average auxiliary engine power and load factors used to estimate emissions. The load factors are assumed to be the same for all activity modes.

Table 4-34. Average OGV Auxiliary Engine Power and Load Factors

Codes	Vessel Type	Engine Type	Engine Power (kW)	Load Factor
BU	Bulk	4-stroke	1,132	0.33
CC	Container	4-stroke	2,918	0.33
GC	General Cargo	4-stroke	913	0.33
CH	Chemical Carrier	4-stroke	2,356	0.33
RR	Roll on-Roll off (RORO)	4-stroke	2,518	0.33
RF	Refrigerated Cargo (Reefer)	4-stroke	6,000	0.50
TA	Tanker	4-stroke	2,214	0.50
VE	Car Carrier	4-stroke	2,181	0.33
PA	Passenger	4-stroke	6,000	0.50
MS	Miscellaneous	4-stroke	1,000	0.33

For propulsion engines, the average engine power and the engine type were obtained from the EPA report *Commercial Marine Activity for Deep Sea Ports in the United States* (*Deep Sea Ports*) (EPA, 1999c). This report presents data for vessels that called on the Delaware River Area ports during calendar year 1996. Note that the Delaware River Area includes ports in Delaware, New Jersey and Pennsylvania, which are located on the Delaware River. The number of calls by vessel type, and engine type is presented for specific DWT ranges. The average engine power is also given.

For each vessel type and DWT range, DNREC calculated the ratio between the vessel calls for each engine type to the total number of calls in 1996. An example (using general cargo vessel calls) of how the engine type ratios were calculated is given below to illustrate this process. Table 4-35 provides a list of calculated ratios for general cargo vessels.

$$
\begin{aligned}
Ratio\ of\ Engine\,Types &= \frac{Number\ of\ Calls_{\ (Vessel\,Type,\,DWT\ Range,\,Engine\,Type)}}{Total\ Number\ of\ Calls_{\ (Vessel\,Type,DWT\ Range)}} \\
&= \frac{132\,Calls_{\ (GC,<15{,}000DWT,\,2\text{-}stroke)}}{299_{(GC,<15{,}000DWT}\ )} \\
&= 0.4415
\end{aligned}
$$

Next, DNREC counted the number of vessel calls on the Delaware River Area during 2002 for each vessel type and DWT range. DNREC then multiplied the 2002 vessel calls by the ratio of calls for each engine type developed for 1996.

Table 4-35. Example of 1996 Engine Ratio Types for General Cargo Vessels

Vessel Code	DWT Range	Engine Type	Average Propulsion Engine Power (hp)	Delaware River Area Vessel Calls in 1996	Delaware River Area 1996 Ratio of Engine Types
GC	<15,000	2-stroke	5,784	132	0.4415
		4-stroke	3,944	166	0.5552
		Steam turbine	ND	1	0.0033
GC	15,000 - 30,000	2-stroke	10,456	90	0.8491
		4-stroke	7,536	16	0.1509
GC	30,000 - 45,000	2-stroke	12,876	8	1.0000
GC	> 45,000	2-stroke	12,170	1	1.0000

$$\begin{aligned} Calls_{(VesselType, DWTRange, EngineType)} &= 2002\ Calls_{(VesselType, DWTRange)} \times Ratio\ of\ Engine\ Types \\ &= 201\ Calls_{(GC, <15{,}000\ DWT)} \times 0.4415_{(GC, <15{,}000\ DWT,\ 2\text{-}stroke)} \\ &= 89\ Calls_{(GC, <15{,}000\ DWT,\ 2\text{-}stroke)} \end{aligned}$$

This procedure provided the estimated number of 2002 vessel calls on the Delaware River Area for each vessel type and DWT range by engine type. As an example, the results for general cargo vessels calls on the Delaware River Area are given below in Table 4-36.

Table 4-36. 2002 General Cargo Delaware River Area Vessels Calls

Vessel Code	DWT Range	Vessel Calls in 2002 by Vessel Type	Engine Type	1996 Ratio of Engine Types	Vessel Calls in 2002 by Vessel and Engine Type
GC	<15,000	201	2-stroke	0.4415	89
			4-stroke	0.5552	112
			Steam turbine	0.0033	< 1
GC	15,000 - 30,000	114	2-stroke	0.8491	97
			4-stroke	0.1509	17
GC	30,000 - 45,000	58	2-stroke	1.0000	58
GC	> 45,000	81	2-stroke	1.0000	81

The average engine power estimated for vessel calls on the Delaware River Area in 1996 was then assigned to the appropriate vessel/engine category for the vessel calls during 2002. The process was repeated for all vessel types. Table 4-37 presents the assigned propulsion engine power and the number of calls by vessel type, DWT Range and engine type for calls on the Delaware River Area in 2002.

In order to calculate underway emissions for Delaware, the number of calls (by vessel type and DWT range) had to be allocated to each port. For the State of Delaware, these ports are Port of Wilmington, Delaware Terminal, Premcor, and Oceanport. For the States of Pennsylvania and

New Jersey, DNREC assumed all vessels traveled from the breakwater to beyond the Delaware state line (PA/DE to the Sea). Vessels calling on New Jersey and Pennsylvania ports must be included in underway emissions calculations for the Delaware since the vessels travel on the Delaware portion of the river. These vessel calls were handled separately from the Delaware calls; therefore the port allocation ratio for these calls is 1.0.

Table 4-37. Average Propulsion Engine Power and the 2002 Number of Calls for OGVs Calling on the Delaware River Area (DE, NJ and PA)

Code	DWT Range	Engine Type	Power (hp)	Calls	Code	DWT Range	Engine Type	Power (hp)	Calls
BU	<25,000	2-stroke	9,665	66	RR	<15,000	2-stroke	8,280	22
BU	<25,000	4-stroke	7,504	11	RR	<15,000	4-stroke	8,553	24
BU	25,000 - 35,000	2-stroke	9,696	71	RR	15,000 - 30,000	2-stroke	12,852	33
BU	35,000 - 45,000	2-stroke	10,320	78	RR	>30,000	2-stroke	16,328	11
BU	> 45,000	2-stroke	16,328	104	TA	<30,000	2-stroke	10,008	172
CC	<25,000	2-stroke	17,757	173	TA	<30,000	4-stroke	7,077	41
CC	<25,000	4-stroke	10,898	91	TA	<30,000	Steam	14,646	17
CC	25,000 - 35,000	2-stroke	16,327	248	TA	30,000 - 60,000	2-stroke	12,616	127
CH	<25,000	2-stroke	9,665	3	TA	30,000 - 60,000	4-stroke	15,360	8
CH	<25,000	4-stroke	7,504	1	TA	30,000 - 60,000	Steam	15,498	88
CH	25,000 - 35,000	2-stroke	9,696	2	TA	60,000 - 90,000	2-stroke	16,026	59
CH	35,000 - 45,000	2-stroke	10,320	2	TA	60,000 - 90,000	4-stroke	14,305	8
GC	<15,000	2-stroke	5,784	89	TA	90,000 - 120,000	2-stroke	15,451	162
GC	<15,000	4-stroke	3,944	112	TA	90,000 - 120,000	Steam	23,923	3
GC	15,000 - 30,000	2-stroke	10,456	97	TA	120,000 - 150,000	2-stroke	23,046	88
GC	15,000 - 30,000	4-stroke	7,536	17	TA	> 150,000	2-stroke	25,559	60
GC	30,000 - 45,000	2-stroke	12,876	58	TA	> 150,000	Steam	36,324	19
GC	> 45,000	2-stroke	12,170	81	VE	<12,500	2-stroke	11,877	31
PA	5,000 - 10,000	4-stroke	20,776	8	VE	<12,500	4-stroke	13,150	6
RF	<5,000	2-stroke	9,553	20	VE	12,500 - 15,000	2-stroke	12,859	46
RF	<5,000	4-stroke	7,048	11	VE	12,500 - 15,000	4-stroke	14,770	8
RF	5,000 - 10,000	2-stroke	9,706	73	VE	15,000 - 17,500	2-stroke	13,911	52
RF	5,000 - 10,000	4-stroke	6,837	14	VE	> 17,500	2-stroke	15,224	70
RF	10,000 - 15,000	2-stroke	12,500	110	MS	< 1,000	2-stroke	2,400	6
RF	10,000 - 15,000	4-stroke	15,672	2	MS	< 1,000	4-stroke	1,293	3
RF	15,000-25,000	2-stroke	18,467	228					

For Delaware port vessel calls, DNREC calculated the ratio between the number of calls to each Delaware port by vessel type and DWT range to the total number of calls to Delaware ports by vessel type and DWT range. An example of how the engine type ratios for all general cargo vessels were calculated is given below to illustrate this process.

$$Ratio\ of\ Ports = \frac{Number\ of\ Calls_{\ (Vessel\ Type,\ DWT\ Range,\ Port)}}{Total\ Number\ of\ Calls_{\ (Vessel\ Type, DWT\ Range)}}$$

$$= \frac{3\ Calls_{\ (GC, 15\text{-}30\ DWT, Oceanport)}}{5\ Calls_{\ (GC, 15\text{-}30\ DWT}\ )} = 0.60$$

Table 4-38 provides a list of the calculated ratios for general cargo vessels.

Table 4-38. Engine Type Ratios for All General Cargo Vessels Calling on Delaware Ports

Codes	DWT Range	Total Calls	Port	Calls at Ports	Port Ratio
GC	< 15,000	9	WILM (PORT) DE	9	1.00
GC	15,000-30,000	5	OCEANPORT DE	3	0.60
			WILM (PORT) DE	2	0.40
GC	30,000-45,000	1	WILM (PORT) DE	1	1.00
GC	> 45,000	2	WILM (PORT) DE	2	1.00

DNREC then multiplied the 2002 vessel calls (by vessel type, DWT range, and engine type) by the ratio of calls for each port. Rounding is required since a vessel call must be an integer value.

$$
\begin{aligned}
Calls_{(VesselType,DWTRange,EngineType,Port)} &= 2002\ Calls_{(VesselType,DWTRange,EngineType)} \times Ratio\ of\ Ports \\
&= 4\ Calls_{(GC,15\text{-}30\ DWT,2stroke)} \times 0.60_{(GC,15\text{-}30\ DWT,Oceanport)} \\
&= 2\ Calls_{(GC,15\text{-}30\ DWT,\ 2\text{-}stroke,Oceanport,\ )}
\end{aligned}
$$

This procedure provided the estimated number of 2002 vessel calls for each vessel type, DWT range, and engine type by port. The results for general cargo vessels are given below in Table 4-39. The call data by vessel type, DWT range, engine type, and port are located in the OGV database files that accompany this report.

Table 4-39. General Cargo Calls by Engine Type & Port

Codes	DWT Range	Engine Type	Power (hp)	Calls by Engine	Port Ratio	Port	Calls by Engine & Port
GC	<15,000	2-stroke	5,784	4	1.00	Wilmington	4
GC	<15,000	4-stroke	3,944	4	1.00	Wilmington	4
GC	15,000 - 30,000	2-stroke	10,456	4	0.60	Oceanport	2
					0.40	Wilmington	2
GC	15,000 - 30,000	4-stroke	7,536	1	0.60	Oceanport	1
					0.40	Wilmington	0
GC	30,000 - 45,000	2-stroke	12,876	1	1.00	Wilmington	1
GC	> 45,000	2-stroke	12,170	2	1.00	Wilmington	2

Propulsion engine load factors specific to Delaware River ports for the various modes of operation, presented in Table 4-40, were obtained from EPA's *Deep Sea Ports* (EPA, 1999c).

For each vessel type, the average time spent in cruise, maneuver, and hotel modes was obtained from *Deep Sea Ports* (EPA, 1999c). For the RSZ mode, DNREC calculated the time-in-mode based on the distance to each port and an average OGV vessel speed of 10 knots. Table 4-41 presents the time-in-mode by vessel type and port. An example is given below for the Port of Wilmington. Note that one vessel call requires 2 trips, one inbound trip and one outbound trip.

Table 4-40. Propulsion Engine Load Factors for Ocean-Going Vessels

Codes	Vessel Type	Engine Load Factors by Mode		
		Cruise	Maneuver	RSZ
BU	Bulk	0.80	0.20	0.40
CC	Container	0.80	0.15	0.30
GC	General Cargo	0.80	0.20	0.35
CH	Chemical Carrier	0.80	0.20	0.40
RR	RORO	0.80	0.15	0.30
RF	Reefer	0.80	0.15	0.30
TA	Tanker	0.80	0.20	0.40
VE	Car Carrier	0.80	0.15	0.30
PA	Passenger	0.80	0.10	0.20
MS	Miscellaneous	0.80	0.15	0.30

$$
\begin{aligned}
Time\ in\ RSZ &= \frac{Distance\ from\ Breakwater\ to\ Port}{Vessel\ Speed} \times 2 trips \\
&= \frac{66.5\ nautical\ miles}{10\ knots} \times 2 trips \\
&= 13.3\ hours
\end{aligned}
$$

Table 4-41. Average Time-in-Mode by Vessel Type and Port

Codes	Ship Type	Cruise (hr/call)	Maneuver (hr/call)	Hotel (hr/call)	Port	RSZ (hr/call)
BU	Bulk	3.4	1.7	95.8	DE/PA to Sea	14.4
CC	Container	2.7	1.1	33.5	Wilmington	13.3
GC	General Cargo	3.6	1.6	91.3	DE Terminal	13.0
CH	Chemical Carrier	3.4	1.7	95.8	Oceanport	12.0
RR	RORO	3.3	1.2	60.7	Premcor	10.8
RF	Reefer	2.7	1.5	63.0		
TA	Tanker	3.4	2.4	85.1		
VE	Car Carrier	3.2	1.2	22.7		
PA	Passenger	2.4	1.1	20.5		
MS	Miscellaneous	3.6	1.3	44.0		

While the engine activity equation is the same for propulsion engines and auxiliary engines, the activity for the two engines must be kept separate since they have different emissions factors. An example is given below for RSZ mode of general cargo vessels with DWT of 15,000-30,000 and 2-stroke engines that call to Oceanport.

For the propulsion engine:

$$
\begin{aligned}
Activity_{mode} &= Power \times LoadFactor \times Time_{mode} \times Calls \\
&= 10{,}456\ hp \times \frac{0.7457\ kW}{hp} \times 0.35 \times 12\ hours \times 2\ calls \\
&= 65{,}495\ kW\text{ - }hours
\end{aligned}
$$

For the auxiliary engine:

$$
\begin{aligned}
Activity_{mode} &= Power \times LoadFactor \times Time_{mode} \times Calls \\
&= 913\, kW \times 0.33 \times 12\, hours \times 2\, calls \\
&= 7{,}231\, kW\text{ - }hours
\end{aligned}
$$

Chesapeake & Delaware (C&D) Canal Vessels and Towboats

DNREC obtained data on vessels passing through the C&D Canal during calendar year 2002 from *Waterborne Commerce of the United States* (USACE, 2004a). Self-propelled vessels were categorized as towboat, dry cargo vessel, or tanker. Non-self-propelled vessels, typically referred to as barges, are not included in the vessel trip counts. Table 4-42 presents the number of trips through the C&D Canal.

Table 4-42. Number of Trips through the C&D Canal in 2002

Vessel Type	Number of Trips
Towboat	4,235
Dry Cargo Vessel	555
Tanker	40

The only activity in the C&D canal is transit (RSZ mode). The distance between the Maryland-Delaware border and the Delaware River is 11.2 nautical miles, based on information provided in the 1999 CMV emissions inventory for the State of Delaware (DNREC, 2002). The average vessel speed through the canal was assumed to be 10 knots (EPA 1999a). Therefore, the average transit time through the C&D Canal is:

$$Time_{C\&D\ transit} = \frac{distance}{speed} = \frac{11.2\ nautical\ miles}{10\ knots} = 1.12\ hours\ per\ trip$$

For dry cargo vessels and tankers, propulsion and auxiliary engine power were based on the information presented above for OGVs. DNREC estimated the average propulsion engine power by weighting the engine power with the number of 1996 vessel calls per engine type. For towboat engine data, DNREC relied on survey information collected for the Port of New York, New Jersey and Long Island (NYNJ, 2003). DNREC assumed the load factors were similar to those reported for towboats in the Port of New York, New Jersey and Long Island survey. Table 4-43 presents the average engine size and load factors for the various types of vessels using the C&D Canal.

Table 4-43. Average Propulsion and Auxiliary Engine Power and Load Factors for C&D Canal Vessels

	Average Engine Size		RSZ Load Factor	
Vessel Type	Propulsion (kW)	Auxiliary (kW)	Propulsion	Auxiliary
Dry cargo	4,686	913	0.6875	0.65
Tanker	11,060	2,214	0.6875	0.65
Towboat	3,183	913	0.6875	0.65

Delaware River Towboats

The number of towboat trips along the Delaware River area was obtained from *Waterborne Commerce* (USACE, 2004a). Each trip was assumed to be a unit tow. The Delaware River data includes trips for both the POW and the C&D Canal. DNREC subtracted the number of towboat trips for the POW and the C&D Canal from the number of trips on the Delaware River. The towboats coming from and going to the Port of Wilmington and the C&D Canal travel both south and north on the Delaware River. Therefore, DNREC split these number of towboat trips evenly. The number of trips is given in Table 4-44.

Table 4-44. Towboat Trips and Time-in-Mode for the Delaware River

Parameter	Units	DE River	POW South	POW North	C&D South	C&D North
Trips[a]		16,414	552	552	2,118	2,118
Distance	miles	83.1	76.5	6.6	62.5	20.6
Speed	mph	11.5	11.5	11.5	11.5	11.5
RSZ	hr/trip	7.2	6.6	0.6	5.4	1.8
Maneuver	hr/trip	0	1.0	1.0	1.0	1.0
Total RSZ Time	**hours**	**118,529**	**3,670**	**317**	**11,500**	**3,791**
Total Man. Time	**hours**	**0**	**552**	**552**	**2,118**	**2,118**

[a]Assumes 50% of the vessels travel North and 50% travel South for POW and C&D

Mileage for each trip was obtained from Table 4-33. The average vessel speed was assumed to be 10 knots (EPA, 1999c). The time in transit per trip was estimated from the average vessel speed and the distance to each port. The maneuvering time for towboats entering or leaving the Port of Wilmington and the C&D Canal was assumed to be one hour per EPA's *Deep Sea Ports* (EPA, 1999c). Propulsion and auxiliary engine power and load factors were obtained from Table 4-43 for towboats.

Tug-Assist Vessels

DNREC calculated propulsion and auxiliary engine activity for tug-assist vessels. Activity was calculated for two modes: 1) transit mode, which refers to taking the pilot to the vessel and escorting the vessel to the port; and 2) assist mode, which refers to maneuvering the vessel into the berth and securing the dock lines. DNREC did not estimate emissions from hotelling of tug-assist vessels due to lack of activity data.

Tug-assist vessels are not accounted for in the towboat/tugboat activity reported in *Waterborne Commerce.* More than one tug is generally required to assist an OGV during a call. DNREC obtained the average number of assist tugs required per call for each vessel type from the survey information collected for the Port of New York, New Jersey and Long Island (NYNJ, 2003). Table 4-45 presents the number of assist tug vessels required for each call by vessel type.

The number of OGV vessel calls in 2002 by vessel type and port was obtained from the 2002 OGV activity. DNREC multiplied the number calls by the number of tugs required to assist each vessel type. An example using general cargo vessels assisted to Oceanport is given below. DNREC obtained average engine power and load factors from the survey information collected for the Port of New York, New Jersey and Long Island (NYNJ, 2003). Table 4-46 presents the average tug-assist vessel engine data.

$$\begin{aligned} TugCalls_{(VesselType,Port)} &= 2002\ OGV\ Calls_{(VesselType,Port)} \times Tugs_{(VesselType)} \\ &= 3\ Calls_{(GC,Oceanport)} \times 3_{(GC)} \\ &= 9\ Tug\ Calls_{(GC,Oceanport)} \end{aligned}$$

Table 4-45. Average Number of Assist Tugs Required Per Vessel Call

Codes	Number of Assist Tugs	Codes	Number of Assist Tugs
RF	4	BU	3
CC	4	RR	3
CH	3	PA	2
GC	3	MS	2
TA	3	VE	1.5

For transit mode, DNREC applied the RSZ time developed for each port in the 2002 OGV activity data and presented in Table 4-41. The time to assist the vessels with berthing is assumed to be 20% more time than the time spent maneuvering by the OGV. DNREC multiplied the maneuvering time given in Table 4-41 by 120% to obtain the time spent in assist mode. Table 4-47 presents the average time spent assisting OGV vessels.

Table 4-46. Engine Propulsion and Auxiliary Engine Power and Load Factors for Tug-Assist Vessels

Engine	Power (kW)	Load Factor	
		Escort	Assist
Propulsion	2,908	0.40	0.68
Auxiliary	90	0.50	0.50

Table 4-47. Average Time in Assist Mode for Tugs

Codes	Assist Time (hr)	Codes	Assist Time (hr)
BU	2.04	RF	1.80
CC	1.32	RR	1.44
CH	2.04	TA	2.88
GC	1.92	VE	1.44
PA	1.32	MS	1.56

Dredging

Maintenance dredging is performed routinely on the Delaware River to keep the channels to their required depths. Dredging involves multiple vessels, including dredges, assist tugs, and generator barges that provide additional power. Estimating emissions from dredging vessel engine activity is time-consuming. Therefore, DNREC developed emissions based on the volume of material dredged during calendar year 2002 rather than engine activity in kilowatt-hours.

DNREC obtained the dredging activity data from both the USACE and from within DNREC. The amount of material dredged by the USACE was obtained directly from the USACE Pennsylvania District Office (USACE, 2004b). DNREC obtained the amount of material dredged by contractors from the USACE report on dredging contracts awarded for the year 2002 (USACE, 2004c). DNREC also contacted the Delaware Division of Soil and Water Conservation to obtain the amount of material dredged by the Division (DSWC, 2004). Table 4-48 presents the estimated amount of material dredged and the type of dredge used.

Table 4-48. Material Dredged in the Delaware River Area during 2002

Project Location	Type of Equipment	Total Material Dredged (cubic yards)
PA to the Sea	Hydraulic Dredge	3,100,000
Mispillion River	Hydraulic Dredge	22,500
Murderkill River	Hydraulic Dredge	25,000
Wilmington Harbor	Hydraulic Dredge	465,600
Cedar Creek/Slaughter Beach	Hydraulic Dredge	8,606

DNREC assumed all the dredging activity is maintenance dredging. New cut dredging results in higher emissions, therefore this assumption may result in lower emission estimates than are actually occurring in the area.

Ferries

The Cape May-Lewes Ferry and the Three Forts Ferry were identified as ferry services in the Delaware. DNREC obtained the number of trips for the year 2002 from the ferry schedules (DRBA, 2004a; CMLF, 2004). Times for maneuvering and idling at dock were obtained from EPA's Deep Sea Ports (EPA, 1999c). For summer workweek activity, DNREC obtained the average number of weekday trips during the months of June, July and August from the Delaware River and Bay Authority staff and the Delaware Division of Parks and Recreation (DRBA, 2004b; DDPR, 2004). Table 4-49 presents time-in-mode data and distances for the ferries.

Table 4-49. Number of Trips, Time-in-Mode, and Distance for Delaware Ferries

Parameter	Cape May-Lewes	Three Forts
Number of trips (yearly)	2,465	1,330
Number of trips (summer)[a]	1,200	880
Trip distance (miles)	17[b]	2
Speed (knots)	16	10
Average Time (hr/trip)		
Cruise	1.3	0.5
Maneuvering	0.167	0.1666
Idle	0.333	0.333

[a]Summer defined as 13 weeks for CML Ferry and 11 weeks for the Three Forts Ferry.
[b]Trip distance is the distance traveled in Delaware

DNREC obtained the propulsion and auxiliary engine power from the websites for the Delaware Division of Parks and Recreation and Delaware River and Bay Authority (DDPR, 2004; DRBA, 2004a). Load factors were obtained from EPA's *Deep Sea Ports* (EPA, 1999c). Table 4-50 presents engine data used to estimate ferry activity.

Table 4-50. Engine Power and Load Factors for Ferries

Ferry	Engine	Engine Power (hp)	Load Factor		
			Cruise	Maneuver	Idling
Cape May-Lewes	Propulsion	4000	0.75	0.20	0
	Auxiliary	300	0.65	0.65	0.65
Three Forts	Propulsion	550	0.75	0.20	0
	Auxiliary	195	0.65	0.65	0.65

4.5.2 Spatial Allocation

DNREC developed county allocation factors for CMV activity data based on the location of the activity on the various waterways and length of the waterway segment. In developing county allocation factors, DNREC assumed that from latitude 39°30' to 25 miles beyond the mouth of the Delaware Bay, the activity are split evenly between Delaware and New Jersey since the ship channel roughly corresponds to the boundary between the two states. Above latitude 39°30', all emissions are allocated to Delaware since the entire breadth of the river is under Delaware's jurisdiction. Allocations were developed for each activity mode, since the activity takes place in different areas depending on the mode. Table 4-51 presents the distances used in developing county allocation factors for vessels traveling through Delaware to ports north of the state line.

Table 4-51. County Allocation Factors for PA/DE to the Sea

PA/DE to the Sea	Distance (miles)	Distance Ratio	DE-NJ Activity Ratio	Total RSZ Alloc. Factor
PA/DE line to Latitude 39°30'	25.5	0.3069	1.0	0.3069
Latitude 39°30' to NCC/KC Line	9.0	0.1083	0.5	0.0542
New Castle County	34.5			0.3610
Kent County	32.8	0.3947	0.5	0.1974
Sussex County	15.8	0.1901	0.5	0.0951
Total Distance	**83.1**			

Ocean-Going Vessels

Cruise mode for OGVs occurs 25 miles out from the breakwater to the breakwater. The activity data was first split evenly between Delaware and New Jersey. The Delaware portion was then allocated to Sussex County since all cruise activity takes place off the Sussex County coast.

For OGV maneuvering and hotelling modes, the activity is allocated to the county in which the port is located. All the Delaware ports are located in New Castle County. Therefore, all maneuvering and hotelling activity was allocated to occur in New Castle County.

For the RSZ mode, county allocation factors were developed for the four ports in Delaware (Port of Wilmington, Delaware Terminal, Oceanport, and Premcor) and from the Pennsylvania-Delaware border to the breakwater (PA/DE to the Sea). An example is given below for developing the county allocations factors for PA/DE to the Sea.

The total distance between the Pennsylvania-Delaware border and the breakwater is 83.1 miles. The distance between each county and the distance from the county line to latitude 39°30' was obtained from the Delaware 1999 emissions inventory (DNREC, 2002). The distance ratio is the distance for each segment divided by the total distance. This ratio was multiplied by the ratio of the activity split between Delaware and New Jersey. For PA/DE to the Sea, the county allocation factor for Kent County is calculated as:

$$KentCounty = (32.8 / 83.1) \times 0.5 = .1974$$

The activity data for each port was multiplied by the county allocation factors (CAF) to estimate the activity in each county. Continuing the example for general cargo vessels with 2-stroke engines in RSZ mode that call on Oceanport, the total activity is 65,495 kW-hours. The activity in New Castle County is calculated as:

$$\begin{aligned}
Activity_{(mode,county,port,vessel,engine)} &= Activity_{(mode,port,vessel,engine)} \times CAF_{(port,RSZ)} \\
&= 65{,}495\ kW\text{ - }hours_{(NewCastle,GC,2-st)} \times 0.2307_{(Oceanport,RSZ)} \\
&= 15{,}110\ kW\text{ - }hours_{(RSZ,New\ Castle,Oceanport,GC,2\text{-}st)}
\end{aligned}$$

Table 4-52 presents the county allocation factors for the waterways and ports that were developed using this methodology. The C&D North/South and POW North/South factors were only used for towboats.

C&D Canal, Delaware River, and POW Towboats

All activity for the C&D Canal was allocated to New Castle County, the location of the Canal. Transit and maneuvering mode activity data were estimated for towboats on the Delaware River. As stated previously, towboats on the Delaware River were assumed to travel the full distance from the Delaware-Pennsylvania border to the Sea. However, for the Port of Wilmington and the C&D Canal, half the trips were assumed to head north and half the trips were assumed to head south on the Delaware River. Transit mode activity was allocated using the same methodology used for OGV RSZ activity. Distance and activity ratios were developed for each waterway. The activity was then multiplied by the CAFs provided in Table 4-52.

Tug-Assist Vessels

Transit and maneuvering mode activity data were estimated for tug-assist vessels on the Delaware River. Assist (maneuvering) activity is assumed to take place in port, therefore this activity was allocated to New Castle County. Transit mode activity was allocated using the same methodology developed for OGV RSZ activity. Distance and activity ratios were developed for each waterway. The activity was then multiplied by the CAFs provided in Table 4-52.

Table 4-52. County Allocation Factors for the Waterways and Ports Used for the Reduced Speed Zone, Transit, and Escort Modes

County	Port/Waterway	County Allocation Factor
New Castle County	PA to Sea	0.3610
Kent County	PA to Sea	0.1974
Sussex County	PA to Sea	0.0951
New Castle County	Delaware Terminal	0.3059
Kent County	Delaware Terminal	0.2144
Sussex County	Delaware Terminal	0.1033
New Castle County	Premcor	0.1451
Kent County	Premcor	0.2640
Sussex County	Premcor	0.1272
New Castle County	Oceanport	0.2307
Kent County	Oceanport	0.2376
Sussex County	Oceanport	0.1145
New Castle County	POW South	0.3059
Kent County	POW South	0.2144
Sussex County	POW South	0.1033
New Castle County	POW North	1.0000
New Castle County	C&D South	0.1504
Kent County	C&D South	0.2624
Sussex County	C&D South	0.1264
New Castle County	C&D North	1.0000
New Castle County	C&D East	1.0000

Dredging and Ferries

CAFs were developed specifically for allocating dredging in the Delaware River. The entire project length was reported by the USACE Pennsylvania District Office as 120 miles, which includes 36.9 miles above the PA/DE border. The CAFs also account for the activity split between Delaware and New Jersey below the latitude of $39^o30'$. The activity was then multiplied by the CAFs to produce county-level activity. For the other dredging areas, the activity was allocated based on the location of the dredging. The Mispillion River is located on the border of Kent and Sussex Counties, and thus emissions were split between the two counties. Table 4-53 presents the county allocation factors for dredging.

Table 4-53. County Allocation Factors for Dredging

Project Location	County	County Allocation Ratio
PA to the Sea	New Castle	0.2500
	Kent	0.1367
	Sussex	0.0658
Mispillion River	Kent	0.5000
	Sussex	0.5000
Murderkill River	Kent	1.0
Wilmington Harbor	New Castle	1.0
Cedar Creek/Slaughter Beach	Sussex	1.0

The Cape-May Lewes Ferry activity data was split evenly between Delaware and New Jersey. While the Three Forts Ferry travels to Fort Mott on the New Jersey side of the Delaware River, at that latitude, Delaware's jurisdictional waters extend the breadth of the river. Therefore, all activity for the Three Forts Ferry was allocated to Delaware. Based on the ferry location, DNREC allocated all Delaware-assigned activity for the Cape May-Lewes Ferry to Sussex County and all activity for the Three Forts Ferry to New Castle County.

4.5.3 Emission Factors

The EPA published revised emission factors as a result of the emissions inventories developed for the CMV sector Regulatory Impact Analysis reports (EPA, 1999a; EPA, 2003). Emission factors are based on EPA engine category definitions. Using EPA methodologies, DNREC placed each propulsion and auxiliary engine in an EPA Marine Engine Category based on the vessel type (EPA 2001; EPA, 2002). Table 4-54 presents DNREC's assumptions regarding EPA CMV engine categories.

Table 4-54. EPA Marine Engine Category by Vessel Type

Vessel Type	Propulsion	Auxiliary	Vessel Type	Propulsion	Auxiliary
Bulk	Cat 3	Cat 2	Car Carrier	Cat 3	Cat 2
Container	Cat 3	Cat 2	Passenger	Cat 3	Cat 3
General Cargo	Cat 3	Cat 2	Miscellaneous	Cat 3	Cat 2
Chemical Carrier	Cat 3	Cat 2	Towboat	Cat 2	Cat 1
RORO	Cat 3	Cat 2	Tug Assist	Cat 2	Cat 1
Reefer	Cat 3	Cat 3	Ferry	Cat 2	Cat 1
Tanker	Cat 3	Cat 2			

DNREC obtained Category 3 engines emission factors for NO_x, HC (assumed equivalent to VOC), and CO from EPA (EPA, 2002). Category 1 and 2 engine emission factors for NO_x, HC, and CO were obtained from (EPA, 1999a). Tables 4-55 and 4-56 present the emission factors.

Table 4-55. Emission Factors for Category 3 Engines

Mode	Engine	VOC g/kW-hr	NO_x g/kW-hr	CO g/kW-hr
Cruise	2-stroke	0.530	23.60	1.10
	4-stroke	0.530	16.60	0.70
	Steam	0.067	2.80	0.30
RSZ	2-stroke	0.530	23.60	1.10
	4-stroke	0.530	16.60	0.70
	Steam	0.067	2.80	0.30
Maneuver	2-stroke	2.803	32.06	8.14
	4-stroke	2.910	22.64	5.94
	Steam	0.067	2.80	0.30
Hotel	2-stroke	0.134	13.36	2.48
	4-stroke	0.134	13.36	2.48
	Steam	0.067	2.80	0.30

Annual emissions were calculated by vessel type, engine type and mode of operation using the county-level activity data in kilowatt-hours. Emissions were calculated by multiplying the activity in kilowatt-hours by the emissions factor in grams per kilowatt-hour and a conversion factor for grams to tons. Continuing with the example for general cargo vessels in RSZ mode, the total activity for vessels calling at all Delaware ports must be summed.

Table 4-56. Emission Factors for Category 1 and 2 Engines

Engine Category	Power [kW]	VOC [g/kW-hr]	NO_x [g/kW-hr]	CO [g/kW-hr]
Category 2	all	0.134	13.36	2.48
Category 1	75-130	0.27	10	1.7
	130-225	0.27	10	1.5
	225-450	0.27	10	1.5
	450-560	0.27	10	1.5
	560-1000	0.27	10	1.5
	1000+	0.27	13	2.5

$$TotalActivity_{(mode,vessel,engine,county)} = \sum_{ports} Activity_{(mode,port,vessel,engine,county)}$$

$$= \quad 15{,}110\ kWhr_{\ (Oceanport)} + 86{,}291\ kWhr_{\ (Wilmington)}$$

$$= \quad 101{,}401\ kW\text{-}hr_{\ (RSZ,GC,2\text{-}st,NewCastle)}$$

Annual emissions for NOx are estimated as:

$$Emissions_{(mode,vessel,engine,county)} = EF_{(Mode,Engine)} \times TotalActivity_{(mode,vessel,engine,county)} \times \frac{1}{CF}$$

$$= \frac{23.60_{(RSZ,Cat3,2\text{-}st)} \times 101{,}401\ kW\text{-}hours_{(RSZ,\ GC,2\text{-}st,New\ Castle,)}}{907{,}184.7\ g/ton}$$

$$= 2.64\ tons\ NO_X\ _{(RSZ,GC,Cat3,2\text{-}st,NewCastle)}$$

where:

EF	=	emission factor by engine type (grams per kilowatt-hour)
Activity	=	rated power of propulsion engine by vessel type (kilowatt-hour),
CF	=	conversion factor (grams per ton).

Dredging

For dredging, emissions were estimated using ratios developed from the emissions estimates for maintenance dredging of the Delaware River Channel. The report "Delaware River Main Channel Deepening Project, Preliminary Emissions Reduction Strategy Report" presents air emissions that would result from the proposed deepening of the Delaware River Channel (USACE, 2003). The report also estimates emissions of criteria pollutants from annual maintenance of the existing Delaware River Channel and berths. The report presents emissions by amount of material dredged for maintenance dredging activity. The estimates include emissions for the dredge, support equipment, mobilization/demobilization towing and setup/teardown. Table 4-57 presents the emission factors for several methods of dredging.

DNREC multiplied the emission factors by the volume of material dredged from the Delaware River area in 2002 to estimate emissions. Emissions from dredging of the Delaware River from

PA to the Sea in New Castle County are used as an example. The volume of material dredged is obtained from Table 4-48 (3,100,000 cubic yards) and the county allocation factor from Table 4-53 (0.2500). First, the activity data is allocated to the county level as follows:

Table 4-57. Emission Factors for Dredging Operations

Type of Equipment	Emission Factors (tons per million cubic yards)		
	VOC	NO_X	CO
Clamshell Dredge/Drillboat	2.1600	171.7946	20.7482
Hopper Dredge	1.9218	208.0370	21.0683
Hydraulic Dredge	0.6277	57.5744	6.4059

$$Volume_{NewCastle}\left(yd^3\right) = Volume_{PAtoSea} \times CAF$$

$$= 3{,}100{,}000\left(yd^3\right) \times 0.2500$$

$$= 775{,}000\left(yd^3\right)$$

Using the emission factors given in Table 4-57:

$$Annual\ Emissions = Volume\left(yd^3\right) \times ER$$

$$= \frac{775{,}000\left(yd^3\right)}{10^6} \times 57.5744\left(\frac{Ton\ NOx}{million\ yd^3}\right)$$

$$= 44.6\ tons\ NO_X$$

4.5.4 Temporal Allocation

All CMV emissions were calculated as annual emissions, except for ferries. For ferries, DNREC estimated the summer work weekday emissions based on the number of ferry trips for a summer work weekday. For all other vessel types, SSWD daily emissions were calculated by multiplying the annual emissions by a temporal allocation factor (TAF).

DNREC reviewed the distribution of vessel calls during summer months for OGV. The number of vessel calls to Delaware ports in the summer months was approximately 24% of the calls. Since the temporal variation in the OGV activity on a monthly or weekly basis was fairly consistent, a uniform temporal profile was used to estimate SSWD emissions. The same assumption was used for towboats and tug-assist vessels as well. No temporal data were obtained for dredging; therefore, DNREC assumed there was no temporal variation in that activity either. For OGVs, towboats, tug-assist vessels, and dredge operation vessels, activity and emissions were allocated evenly using a TAF of 0.00274.

4.5.5 Controls

New EPA emissions standards for Category 1, 2, and 3 commercial marine engines did not take effect until 2004. In addition, Delaware does not currently regulate air pollution from commercial marine engines. Therefore, the 2002 emissions inventory does not include controls for commercial marine engines.

The international NO_x emissions standards proposed by the International Maritime Organization in Annex VI to the International Convention on the Prevention of Pollution from Ships (MARPOL 73/78) affect only Category 3 engines. The standard had not been ratified as of 2002. However, in 1999, many engines manufactured met the emissions standards due to the possibility of retroactive implementation.

DNREC incorporated the expected emissions reductions due to the use of new Category 3 engines installed on vessels calling at Delaware ports and transiting Delaware waters in 2002. The emission reductions and the expected rule penetration were obtained from the EPA Regulatory Support Document for Category 3 engines (EPA, 2003). DNREC estimated the reduction in NO_x for 2002 based on a linear interpolation between the uncontrolled and the control efficiency in year 2010. Table 4-58 presents the expected reductions due to MARPOL Annex VI.

DNREC applied NO_x emission controls to OGVs calling on the Delaware River Area with Category 3, 2-stroke, 4-stroke and auxiliary engines. No controls were applied to steam engines.

Table 4-58. Estimated Reductions in NO_x Emissions for OGV Engines due to MARPOL Annex VI in Year 2002

Engine Type	MARPOL Control Efficiency	2010 Control Efficiency	2002 Rule Penetration	2002 Overall Control Efficiency
Slow Speed	27.8%	13.1%	9%	2.5%
Medium Speed	22.6%	10.6%	9%	2.0%
Auxiliary	12.0%	5.4%	9%	1.1%

$$Controlled\ Emissions_{(mode,vessel,engine,county)} = Emissions_{(mode,vessel,engine,county)} \times (1 - CE_{(engine)} \times RP_{(engine,year)})$$

$$= 2.64\ tons\ NO_{X\ (RSZ,GC,Cat3,2\text{-}st,NewCastle)} \times (1 - 27.8\%_{(Cat3,2\text{-}st)} \times 9\%_{(Cat3,2\text{-}st,2002)})$$

$$= 2.57\ tons\ NO_{X\ (RSZ,Cat3,2\text{-}st,NewCastle)}$$

4.5.6 Results

Table 4-59. 2002 Statewide Annual and SSWD VOC, NO_X, and CO Emissions for Commercial Marine Vessel Engine Exhaust

SCC	Port/ Underway	Fuel Type	Vessel and Mode	Annual (TPY)			SSWD (TPD)		
				VOC	NO_X	CO	VOC	NO_X	CO
2280002100	Port	Diesel	Tugboat - Maneuver	1	106	20	< 0.01	0.29	0.05
			Towboat-Maneuver	2	175	33	< 0.01	0.48	0.09
			Ferries	3	119	23	0.01	0.55	0.10
			Dredging	1	111	12	< 0.01	0.30	0.03
			Total	**7**	**511**	**87**	**0.02**	**1.62**	**0.28**
2280002200	Underway	Diesel	Tugboat-Escort	15	1,460	270	0.04	4.00	0.74
			Towboat-Transit	29	2,838	526	0.08	7.78	1.44
			Total	**45**	**4,298**	**796**	**0.12**	**11.78**	**2.18**
2280003100	Port	Residual	OGV-Hotel and Maneuver	13	802	154	0.04	2.20	0.42
2280003200	Underway	Residual	OGV-Transit	76	3,506	238	0.21	9.60	0.65
228000xxxx	**Total: Commercial Marine Vessels**			**140**	**9,118**	**1,275**	**0.39**	**25.20**	**3.53**

4.5.7 References

CMLF, 2004: Cape May-Lewes Ferry, 2004: Schedule and Fare Information and FAQs web pages. Information retrieved January 12, 2004, from http://www.capemaylewesferry.com/schedfares/schedule.asp

DDPR, 2004: Delaware Division of Parks and Recreation, 2004: Fort Delaware State Park Information Center Staff, personal communication with Cristina Mackay, E.H. Pechan & Associates, Inc., January 13, 2004.

DNREC, 2002: *1999 Periodic Ozone State Implementation Plan for VOC, NOX, and CO*, Department of Natural Resources and Environmental Control, 2002.

DRBA, 2004a: Delaware River and Bay Authority, 2004: Three Forts Ferry Schedule and Fare Information. Information retrieved January 12, 2004, from http://www.threeforts.com/sched.html

DRBA, 2004b: Delaware River and Bay Authority, 2004: Cape May-Lewes Ferry Information Center Staff, personal communication with Cristina Mackay, E.H. Pechan & Associates, Inc., January 12, 2004.

DSWC, 2004: Chuck Williams, Delaware Division of Soil and Water Conservation, personal communication with Paula Hemmer, E.H. Pechan & Associates, Inc., February 6, 2004.

EPA, 1999a: *Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines*. U.S. Environmental Protection Agency, Office of Mobile Sources, Engine Programs and Compliance Division, EPA420-R-99-026, November 1999.

EPA, 1999b: In-Use Marine Diesel Fuel, US Environmental Protection Agency, Office of Mobile Sources, Engine Programs and Compliance Division, EPA 420-R-99-027, August 1999.

EPA, 1999c: *Commercial Marine Activity for Deep Sea Ports in the United States*. U.S. Environmental Protection Agency. Prepared by ARCADIS Geraghty & Miller, Inc. EPA420-R-99-020, September 1999.

EPA, 2001: "Industry Characterization Category 3 Marine Diesel Engines and Vessels (Draft Report)," Prepared for U.S. Environmental Protection Agency, Office of Transportation and Air Quality, Ann Arbor MI, Prepared by E.H. Pechan & Associates, November 2001.

EPA, 2002: *Commercial Marine Emission Inventory Development.* Revised Draft Report, Prepared for the U.S. Environmental Protection Agency, Prepared by ENVIRON International Corp., April 2002.

EPA, 2003: *Final Regulatory Support Document: Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder*. U.S. Environmental Protection Agency, Office of Transportation and Air Quality. EPA420-R-03-004, January 2003.

HARC, 2000: *Houston-Galveston Area Vessel Emissions Inventory.* Prepared by Starcrest Consulting, LLC for the Port of Houston and the Texas Natural Resource Conservation Commission, November 2000.

ME, 2004: "Ship Arrivals for the Delaware River Ports by State" [data files], Maritime Exchange for the Delaware River and Bay, Philadelphia PA, February 5, 2004.

NYNJ, 2003: *The New York, Northern New Jersey, Long Island, Nonattainment Area Commercial Marine Vessel Emissions Inventory*. Port Authority of New York & New Jersey and United States Army Corps of Engineers, New York District. Prepared by Starcrest Consulting Group, LLC, April 2003.

USACE, 2001: "Chesapeake and Delaware Canal Channel Statement." United States Army Corps of Engineers, Philadelphia District, August 3, 2001. http://www.nap.usace.army.mil/channel/CDC-08-03-2001.pdf

USACE, 2003: "Delaware River Main Channel Deepening Project, Preliminary Emissions Reduction Strategy Report," July 2003, U.S. Army Corps of Engineers, Philadelphia District, Prepared by Moffatt and Nichol Engineers, July, 2003.

USACE, 2004a: *Waterborne Commerce of the United States – Calendar Year 2002 – Part 1 Waterways and Harbors Atlantic Coast.* Department of the Army Corps of Engineers, Institute of Water Resources, IWR-WCUS-02-1, September 2003.

USACE, 2004b: Merv Brokke, United States Army Corps of Engineers, Philadelphia District, personal communication with Cristina Mackay E.H. Pechan & Associates, Inc., January 28, 2004.

USACE, 2004c: "US Army Corps Of Engineers Dredging Contracts Awarded; Fiscal Year 2002 Awards", US Army Corps Of Engineers, information retrieved on January 29, 2004 from http://www.iwr.usace.army.mil/ndc/dredge/pdf/awards02.pdf

4.6 Commercial Marine Vessel Loading, Ballasting, and Transit

CMV operations carrying petroleum liquids cause emissions of VOC during loading of product onto barges, during ballasting operations, and during vessel transit within the port area. Emissions from these operations are estimated using the procedure described in *EIIP Volume III,* Chapter 12 (EPA, 2001).

Loading losses occur as a result of organic vapors in “empty” cargo tanks being displaced to the atmosphere by the liquid being loaded into the tanks. Loading losses are usually the largest source of evaporative emissions from petroleum vessels. This activity usually only occurs at refineries or at the terminal at the end of the pipeline where the product is loaded for distribution. However, petroleum liquids shipped in super tankers may unload to barges in a harbor to allow the tanker to enter shallower ports. This operation is referred to as “lightering.”

Ballasting losses are associated with the unloading of petroleum liquids at marine terminals and refinery loading docks. Emissions from ballasting occur as vapor-laden air in the empty cargo tank is displaced to the atmosphere by ballast water being pumped into the tank. U.S. Coast Guard regulation (33 CFR, Part 157) requires that all vessels greater than 150 gross registered tons must have segregated ballast tanks, which eliminates emissions from ballasting in Delaware waters (DNREC, 2002). Therefore, these emissions are assumed to be zero for the 2002 inventory.

Transit losses are similar in many ways to breathing losses associated with petroleum storage. Transit loss is the expulsion of vapor from a vessel compartment through vapor contraction and expansion, which are the result of changes in temperature and barometric pressure. Transit emissions are based on the amount of time that the vessel is in an area. Some ships are equipped with controls for these losses. Emissions are reported under the following SCCs:

Table 4-60. SCCs for Commercial Marine Vessel Loading, Ballasting, and Transit

SCC	Descriptor 1	Descriptor 3	Descriptor 6	Descriptor 8
2505020030	Storage and Transport	Petroleum Product Transport	Marine Vessel	Crude Oil
2505020060	Storage and Transport	Petroleum Product Transport	Marine Vessel	Residual Oil
2505020090	Storage and Transport	Petroleum Product Transport	Marine Vessel	Distillate Oil
2505020120	Storage and Transport	Petroleum Product Transport	Marine Vessel	Gasoline
2505020150	Storage and Transport	Petroleum Product Transport	Marine Vessel	Jet Naphtha

There are more types of petroleum commodities that are reported than listed in the SCCs given above. Fuels and other petroleum liquids transported by CMVs are classified into five major product types of significantly different densities, vapor pressures, and physical compositions. DNREC assigned the various petroleum commodities to an SCC based on the methodology presented in Table 12.4-2 of *EIIP Volume III* (EPA, 2001). Table 4-61 presents the methodology for assigning petroleum commodities to an SCC.

Table 4-61. Petroleum Commodity SCC Classification

Petroleum Commodity	SCC Product Classification
Crude petroleum	Crude oil
Residual fuel oil	Residual oil
Asphalt, tar, and pitch	Residual oil
Petroleum coke	Residual oil
Kerosene	Distillate oil
Distillate fuel oil	Distillate oil
Lube oil and greases	Distillate oil
Petroleum jelly and waxes	Distillate oil
Gasoline	Gasoline
Liquid natural gas	Gasoline
Naphtha and solvents	Jet naphtha
Petroleum products n.e.c.	Jet naphtha

The Federal Standards for Marine Tank Vessel Loading Operations and National Emission Standards for Hazardous Air Pollutants for Marine Tank Vessel Loading Operations were promulgated in 1995. The compliance date for Maximum Achievable Control Technology (MACT) standards was September 19, 1999. It requires large marine loading terminals (i.e., terminals that load either 200 million barrels per year of crude oil, or 10 million barrels per year of gasoline) to reduce emissions of VOC by at least 95 percent. It also requires all other major sources to reduce air toxic emissions by 97 percent. The sources are subject to recordkeeping and reporting requirements as well.

In the State of Delaware, the rule affects marine vessel loading operations at Maritrans, the principal lightering firm in the Delaware River Area, and the Premcor Refinery. The loading activity data reported under the point source inventory for Maritrans and Premcor was not counted as part of the loading activity under this category. However, emissions from evaporative losses during transit were calculated for Premcor and Maritrans.

4.6.1 Activity Data

DNREC based evaporative VOC emissions from marine vessels on the amount and type of petroleum products transported to, from, or through the inventory area via waterways. The waterways under consideration include Delaware's portion of the Delaware River and Bay (DE River), the Chesapeake and Delaware Canal (C&D Canal), and the Port of Wilmington (POW). DNREC obtained the amount and type of petroleum liquids transported through Delaware waterways and shipped from the Port of Wilmington in 2002 from the USACE publication *Waterborne Commerce* for calendar year 2002 (USACE, 2004).

Waterborne Commerce contains information on the foreign and domestic traffic classification (import, domestic, etc.). The types of losses (emission points) expected from a specific operation are determined based on the traffic classification. The emission points for the various traffic classifications are obtained from Table 12.4-1 in *EIIP Volume III* (EPA, 2001).

Loading activity was obtained from *Waterborne Commerce* for the POW. The loading activity data are summarized in Table 4-62. Assumptions for which traffic classification are considered part of loading activity are given below:

Traffic Classification	Assumption
Foreign exports	loaded onto vessels
Domestic coastwise shipments	loaded onto vessels
Domestic internal shipments	loaded onto barges
Domestic internal intra-port	loaded onto barges

Table 4-62. 2002 Loading Activity at the Port of Wilmington

Waterway	Fuel	Rig	Throughput (1,000 tons)
POW	Gasoline	Vessel	0
POW	Residual	Vessel	280
POW	Distillate	Vessel	18
POW	Naphtha	Vessel	35
POW	Gasoline	Barge	0
POW	Residual	Barge	296
POW	Distillate	Barge	61
POW	Naphtha	Barge	0

Transit activity was obtained from *Waterborne Commerce* for the Delaware River and Bay, the C&D Canal, and the POW. DNREC obtained the amount of crude oil received by Premcor from the point source inventory for 2002. Assumptions for which traffic classifications in Waterborne Commerce are considered part of transit activity are given below.

Traffic Classification	Assumption
Foreign imports/exports	transit on vessels
Domestic coastwise receipts/shipments	transit on vessels
Domestic internal receipts/shipments	transit on barges
Domestic internal intra-port	transit on barges

The amount of petroleum product reported by *Waterborne Commerce* as transported on the Delaware River includes the quantity transported to/from the POW and Premcor, and through the C&D Canal. To prevent double counting, DNREC subtracted these quantities from the quantity transported on the Delaware River. Transit emissions for the POW, C&D Canal and Premcor were calculated separately since the transit times are less than the transit time from the breakwater to the Delaware-Pennsylvania border. The transit activity associated with lightering operations conducted by Maritrans was not subtracted from the quantity of crude oil transported on the Delaware River since petroleum product handled by Maritrans is assumed to continue up the Delaware River after lightering. Thus, the amount reported within *Waterborne Commerce* as "Internal/Intraport/ Upbound" was considered the lightered amount. The adjusted transit activity data is summarized in Table 4-63.

The loading and transit activity is reported in units of 1,000 tons. The emissions factors require units of 1,000 gallons. DNREC converted between the mass of petroleum product and the volume of petroleum product using an average product density. The densities were obtained from Appendix A of AP-42 (EPA, 1995). Table 4-64 presents the average density for each petroleum product category.

Table 4-63. Adjusted 2002 Transit Activity Data for the Port of Wilmington, C&D Canal, Premcor and the Delaware River

Fuel	Waterway	Rig	Throughput (1,000 Tons)	Throughput (1,000 Gallons)
Crude	DE River	Vessel	52,883	14,938,766
Crude	Premcor	Vessel	9,437	2,665,754
Crude	POW	Vessel	222	62,713
Distillate	C&D	Barge	328	93,050
Distillate	POW	Barge	204	57,872
Distillate	DE River	Barge	1,773	502,979
Distillate	C&D	Vessel	256	72,624
Distillate	POW	Vessel	20	5,674
Distillate	DE River	Vessel	3,044	863,546
Gasoline	C&D	Barge	1,127	365,316
Gasoline	POW	Barge	5	1,621
Gasoline	DE River	Barge	1,343	435,332
Gasoline	C&D	Vessel	855	277,147
Gasoline	DE River	Vessel	2,265	734,198
Naphtha	C&D	Barge	18	5,625
Naphtha	DE River	Barge	85	26,563
Naphtha	C&D	Vessel	44	13,750
Naphtha	POW	Vessel	52	16,250
Naphtha	DE River	Vessel	1,032	322,500
Residual	C&D	Barge	1,285	326,142
Residual	POW	Barge	510	129,442
Residual	DE River	Barge	1,489	377,919
Residual	C&D	Vessel	1,087	275,888
Residual	POW	Vessel	615	156,091
Residual	DE River	Vessel	6,018	1,527,411

Table 4-64. Average Densities of Petroleum Products

Product	Density (lb/gallon)
Gasoline	6.17
Crude Oil	7.08
Naphtha	6.4
Distillate	7.05
Residual	7.88

To calculate transit emissions, the time vessels and barges travel on Delaware waterways was estimated. Waterway segment distances from Table 4-33 were used to estimate transit times. The vessels coming from the Port of Wilmington (POW) and the C&D Canal travel both south and north on the Delaware River. DNREC split the activity data evenly and assumed half the volume of the petroleum products traveled north on the Delaware River and half traveled south. Transit time for vessels includes travel on Delaware waterways and travel between the Delaware Bay breakwater and 25 miles out to sea (cruise mode). Maneuvering and hotelling times were not considered for transit emissions.

DNREC assumed vessels and barges traveled 10 knots (11.51 mph) in reduced speed zone mode and vessels traveled 11.74 knots (13.51 mph) in cruise mode based on the cruise time for tankers on the Delaware River as identified in *Deep Sea Ports* (EPA, 1999). Table 4-65 presents the transit times for vessels and barges on Delaware waterways. As an example, the transit time for vessels and barges traveling through Delaware at RSZ mode was calculated as:

$$
\begin{aligned}
Time_{transit} &= \frac{Distance\ Traveled\ on\ Waterway}{Vessel\ Speed} \\
&= \frac{83.1\ miles}{11.51\ mph} \times \frac{1\ week}{168\ hours} \\
&= 0.0430\ weeks
\end{aligned}
$$

Table 4-65. Transit Times on Delaware Waterways (weeks/trip)

CMV Type and Mode	DE River	POW South	POW North	C&D East	C&D North	C&D South	Premcor
Barges and vessels in RSZ mode	0.0430	0.0396	0.0034	0.0067	0.0107	0.0323	0.0320
Vessels in cruise mode	0.0072	0.0072	NA	NA	NA	0.0072	0.0072

The county allocation factors for each waterway segment presented in Table 4-52 were used to allocate statewide emissions from the transit of petroleum products to each county. All loading activity occurs at the POW, therefore all the activity was allocated to New Castle County. All vessel transit in cruising mode occurs beyond the breakwater, therefore half of all activity was allocated to Sussex County (the other half was attributed to New Jersey.)

4.6.2 Emission Factors

The only pollutant resulting from this activity is VOC. VOC emissions are a function of the physical and chemical characteristics of both previous and new cargos. DNREC obtained VOC emission factors for crude oil, naphtha, distillate and residual fuel from Table 12.4-5 in EPA's *EIIP Volume III* Chapter 12 (EPA, 2001). VOC emission factors for gasoline loading were obtained from Table 5.2-2 in AP-42. These emission factors, which represent total organics, are summarized in Table 4-66. All products other than crude oil can be assumed to have VOC factors equal to total organic factors. Typical crude oil VOC factors are 15 percent lower than total organic factors due to the presence of methane and ethane in crude. DNREC reduced the crude oil emission factors presented in Table 4-66 by 15 percent.

Table 4-66. VOC Emission Factors for Marine Vessel Loading and Transit

Source Type	Units	Crude Oil[a]	Gasoline	Jet Naphtha	Distillate	Residual
Ship Loading	lbs/ 10^3 gal	0.61	1.8	0.5	0.005	0.00004
Barge Loading	lbs/ 10^3 gal	1.0	3.4	1.2	0.012	0.00009
Transit	lbs/week/10^3 gal	1.3	2.7	0.7	0.005	0.00003

[a]Crude oil emission factors represent total organics, not VOC.

DNREC calculated the VOC emissions from loading of barges and vessels at the POW using the county level activity data. As an example, 17,305 thousand gallons of distillate (converted from 61 thousand tons) was loaded onto barges in New Castle County during calendar year 2002. VOC emissions are calculated using the following equation:

$$
\begin{aligned}
E_{VOC} &= VolumeLoaded_{\text{barge},distillate} \times EF_{VOC,\text{barge},distillate} \\
&= 17{,}305(1{,}000\,gal) \times 0.012\,\frac{\text{lbs}}{(1{,}000\,gal)} \times \frac{1\,ton}{2{,}000\,lbs} \\
&= .0104\,tons
\end{aligned}
$$

DNREC calculated the VOC emissions from transit of barges and vessels on the various waterways using the activity data from Table 4-63 and the allocated transit times from Table 4-65. An example of the emissions calculation is given below.

From Table 4-63, there is 62,542 thousand tons of crude oil transported on the Delaware River. This was converted to a volume basis using the densities given in Table 4-64 to 17,667,233 thousand gallons. Premcor reported 2,665,754 thousand gallons of crude oil handled in 2002 and the POW received 62,713 thousand gallons. Thus, the amount of crude oil passing through Delaware is:

$$
Volume_{transit} = 17{,}667{,}233(10^3\,gal) - 2{,}665{,}754(10^3\,gal) - 62{,}713(10^3\,gal) = 14{,}938{,}766\,(10^3\,gal)
$$

From Table 4-65, the RSZ transit time for vessels is 0.0430 weeks per trip. This value was multiplied by the county allocation factors given in Table 4-52 to arrive at county-level RSZ transit times on the Delaware River. In addition, the cruise time for vessels approaching the Delaware Bay is 0.0072 weeks per trip, which was allocated to Sussex County. The allocated county-level transit times are provided in Table 4-67.

Table 4-67. County Allocation of Transit Time on the Delaware River

Operating Mode	Transit Time (weeks/trip)	County	County Allocation Ratio	Allocated Transit Time (weeks/trip)
RSZ	0.0430	New Castle County	0.3610	0.0155
		Kent County	0.1974	0.0085
		Sussex County	0.0951	0.0041
Cruise	0.0072	Sussex County	0.5000	0.0036

DNREC then calculated the emissions from transit of vessels carrying crude oil on the Delaware River in a given county using the emission factors in Table 4-66. For Kent County, the VOC emissions are calculated as:

$$
E_{VOC} = \frac{Volume_{transit} \times time_{transit,Kent} \times EF_{VOC,transit,crude} \times (100\% - CF_{crude})}{2{,}000\,lbs/ton}
$$

$$
= \frac{14{,}938{,}766(10^3\,gal - trip) \times 0.0085\,\dfrac{weeks}{trip} \times 1.3\,\dfrac{lbs}{(10^3\,gal - weeks)} \times (100\% - 15\%)}{2{,}000\,lbs/ton}
$$

$$
= 63.5\,tons\,VOC
$$

where: EF = emission factor in lbs per 1,000 gallon-weeks
CF = correction factor for TOC to VOC for crude oil

Note that the correction factor is only needed for crude oil.

4.6.3 Temporal Allocation

All CMV loading and transit emissions are calculated as annual emissions. There is no temporal variation in the activity associated with loading and transport of petroleum products on the Delaware River. Therefore, uniform monthly and weekly allocations were assumed for estimating the SSWD values.

4.6.4 Controls

As previously stated, U.S. Coast Guard regulation (33 CFR, Part 157) requires that all vessels greater than 150 gross registered tons must have segregated ballast tanks. This essentially eliminates emissions from ballasting in Delaware waters (DNREC, 2002). The MACT standard applies to terminals that load either 200 million barrels per year of crude oil, or 10 million barrels per year of gasoline. These sources include Maritrans and the Premcor Refinery, which report as point sources. No other controls are assumed for vessel transit.

4.6.5 Results

Table 4-68. 2002 Statewide Annual and SSWD VOC Emissions for Loading and Transport of Petroleum Products

SCC	Petroleum Product Category Description	VOC	
		TPY	TPD
2505020030	Crude Oil	365	1.00
2505020060	Residual Oil	< 1	< 0.01
2505020090	Distillate Oil	< 1	< 0.01
2505020120	Gasoline	75	0.21
2505020150	Jet Naphtha	8	0.02
2505020xxx	**Total: CMV Loading & Transport**	**448**	**1.23**

4.6.6 References

DNREC, 2002: "1999 Periodic Ozone State Implementation Plan for VOC, NO_x, and CO," Delaware Department of Natural Resources and Environmental Control, 2002.

EPA, 1995: *Compilation of Air Pollution Emission Factors, Volume I: Stationary Point and Area Sources,* Section 5.2 - Transportation And Marketing Of Petroleum Liquids, AP-42 (GPO 055-000-00500-1), U.S. Environmental Protection Agency, Research Triangle Park, NC, 1995.

EPA, 1999: *Commercial Marine Activity for Deep Sea Ports in the United States*. U.S. Environmental Protection Agency. Prepared by ARCADIS Geraghty & Miller, Inc. EPA420-R-99-020, September 1999.

EPA, 2001: *Emissions Inventory Improvement Program, Volume III: Chapter 12 Marine Vessel Loading, Ballasting, And Transit Revised Final*, U.S. Environmental Protection Agency, January 2001.

USACE, 2004: *Waterborne Commerce of the United States – Calendar Year 2002 – Part 1 Waterways and Harbors Atlantic Coast.* Department of the Army Corps of Engineers, Institute of Water Resources, IWR-WCUS-02-1, September 2003.